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Technical Report 32-1400

Bioengineering in Space — The Biosatellite Urinalysis Instrument

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Preface

The work described in this report was performed by the Space Sciences Division of the Jet Propulsion Laboratory.

Acknowledgment

The author wishes to acknowledge the efforts of the experiment development team. Among the numerous Laboratory personnel who contributed greatly to the program, the following deserve particular mention: Dr. G. A. Soffen, for establishing the biochemical interface; Drs. J. Rho and P. Geiger, for establishing the chemical reactions; Mr. J. Clark and Mr. H. Fujimoto, for developing the digital control and analog systems to carry out the operational sequencers; Mr. R. Davis, for designing the analyzers and fluid storage systems; Mr. C. McCoy, for the instrument mechanical packaging and electronic system layout design; Mr. S. B. Wheeler, for his fluid storage and fluid system refinements; Mr. J. Tomey, for the data handling system performance; Mr. H. Fujimoto, for guiding the electronics development, fabrication, and de-bugging team; Mr. F. Scheuer, for establishing and maintaining the administrative liaison with the NASA Ames Research Center and the General Electric Co; and Miss M. E. Scally, for preparing this manuscript.

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Abstract

A urinalysis for calcium, creatinine, and creatine is performed four times daily in a 15-lb automated chemical laboratory. This analysis is performed once daily on standard solutions. The instrument contains a fluorometer for the calcium analyzer, and a nephelometer for the creatine and creatinine analyzer. The instrument also contains the electronics to perform logic sequencing, data acquisition, data storage, the power supplies, and the analyzer amplifiers. All the chemicals required for 150 analyses of each constituent (a total of 450 analyses) are stored within the instrument, which is designed for a 30-day orbital spacecraft mission.

The instrument system and the various subsystems' design configuration needed to meet the scientific experiment and flight-program constraints are discussed in this report.

Bioengineering in Space—
The Biosatellite Urinalysis Instrument

I. Introduction

One of the major unknown factors in the development of long-range manned orbital and extended space environmental flights is the effects of weightlessness on man's psychophysiological system. Since man himself cannot be fully instrumented to determine these effects, a program of biological experimentation has been established to increase knowledge of environmental effects upon the physiological system. Through the use of primates and other organisms, information can be obtained relating the effects of weightlessness and other environmental stresses to the physiological response. Sensors can be implanted in specimens to indicate the state of the central nervous system, the cardiovascular system, respiration, body temperature, and the nature and degree of hormone response.

II. The Biosatellite Primate Experiment

Efforts have been made during the past few years to conduct a series of biological experiments in the space environment. These programs, which included the Biologically Instrumented Orbiting Satellite (BIOS) and *Discoverer* flights, did not provide the quantity or quality of data anticipated by the Biosatellite project. Results obtained from projects *Mercury* and *Gemini* provided some information on the effects of weightlessness on man for limited periods of exposure. However, the results obtained from flights of several days to flights of several weeks cannot be extrapolated with certainty. A program of prolonged exposure of the biological system for long periods is required to understand the stresses on man and to define the man-support requirements during future space missions. A program of experiments with biological material exposed to such environments from 3 to 30 days would be a meaningful step toward future progress in manned space flight. The overall objective of the Biosatellite project is the launch, orbital operation, recovery, and post-flight analysis of a series of biological experiments in an earth-orbiting space environment. These experiments would provide data for the determination of the effects of weightlessness, combined radiation and weightlessness, and removal from other earth influences upon biological specimens for periods of from 3 to 30 days.

The 30-day biosatellite primate experiment deals with the influence of weightlessness on a whole organism as complicated as that of a monkey. The macaque (pigtail)

monkey was selected for this program because of his physical size, the ease with which he may be trained, his adaptability to the environmental conditions, his general personality traits, and a basic metabolism which fits within the vehicle's constraints. The four systems being examined during the mission are as follows:

(1) The nervous system.

(2) The cardiovascular system.

(3) The skeletal system.

(4) The muscular and renal systems.

This report presents a detailed description of the instrumentation required to monitor the fourth experiment listed above. Dr. Nello Pace, of the University of California, Berkeley, and Dr. Joon Rho, of JPL are the investigators collaborating on the Pace/Rho primate urinalysis experiment. The purpose of this experiment is to determine the urinary excretion rates of calcium, creatine, and creatinine. To accomplish this, it is necessary to measure the calcium, creatine, and creatinine concentrations in urine sample aliquots collected during successive 6-h intervals throughout the entire 30-day flight. Flight data are telemetered. Pre-flight, flight, and post-flight data enable the evaluation of the effects of weightlessness upon these three metabolic constituents.

A. Pace/Rho Experiment Rationale

At the inception of the Biosatellite program, Dr. Pace proposed to return frozen urine samples for analysis after vehicle recovery. Detailed examination of the requirements and vehicle capabilities showed an inadequate power capacity to maintain the urine in a frozen condition if the reentry vehicle had to survive for some time in the ocean. Hence, the experiment was temporarily set aside. Later, NASA requested JPL to develop an analytical laboratory capable of performing analyses of primate urine in flight during the Biosatellite D and F missions. To meet this requirement, and an abbreviated development time schedule, the experiment was designed to perform in-flight analyses for calcium, creatine, and creatinine for the duration of the flight mission.

B. Spacecraft Conditions and Environment

The 30-day Biosatellite flights utilize a two-stage, thrust-augmented improved *Delta* launch vehicle. This vehicle is the higher-performance long-tank DSV-3N version.

The first stage of the vehicle consists of a *Thor* vehicle, augmented with strap-on Thiokol TX33-52 solid boosters. The second stage is the "improved" *Delta*. The spacecraft is enclosed in a *Nimbus* fairing, which is modified for final access to the spacecraft for coolant umbilical pull-away, and for quick installation after experiment package insertion.

A special biosatellite attach fitting interfaces the spacecraft with the launch vehicle. Separation is accomplished by springs restrained with explosive nuts built into the attach fitting. The attach fitting has modified panels to reduce resonant vibrations.

The spacecraft configuration consists of two major sections: (1) the reentry vehicle, and (2) the adapter section. The reentry vehicle is that portion of the spacecraft containing the recoverable experiment capsule, and deorbit and recovery subsystems. The adapter section contains all of the equipment not required for the deorbit, reentry, or recovery of the experiment capsule. The major components of the spacecraft are the forebody, recovery capsule, thermal cover, thrust cone, and the adapter section (see Fig. 1).

After separation of the spacecraft from the launch vehicle, the angular rates are sensed by rate gyros and controlled with a nitrogen cold-gas reaction jet system. During the orbiting phase, the angular rates are maintained sufficiently low so that the accelerations to which the experiments are subjected are below 10^{-3} g for 95% of the time, and below 10^{-1} g for the remaining time. In other words, the attitude control system merely prevents the vehicle from rotating faster than approximately once in 20 min.

The 30-day mission utilizes a *Gemini*-type fuel cell as the prime source of power. A backup battery is provided to permit recovery of the capsule in the event of total fuel cell failure.

For reentry, the spacecraft must be aligned precisely to its orbital path, facing backward and pitched downward 36 deg. For this, two infrared horizon scanners align the spacecraft in pitch and roll to the deorbit attitude. For yaw, a magnetometer senses the earth's magnetic field. Ground commands transmit data to bias the magnetometer to the direction of the earth's magnetic field lines at the geographical point of retrofire. The magnetometer is used as a reference to line up the spacecraft in yaw with its orbital path. With the required

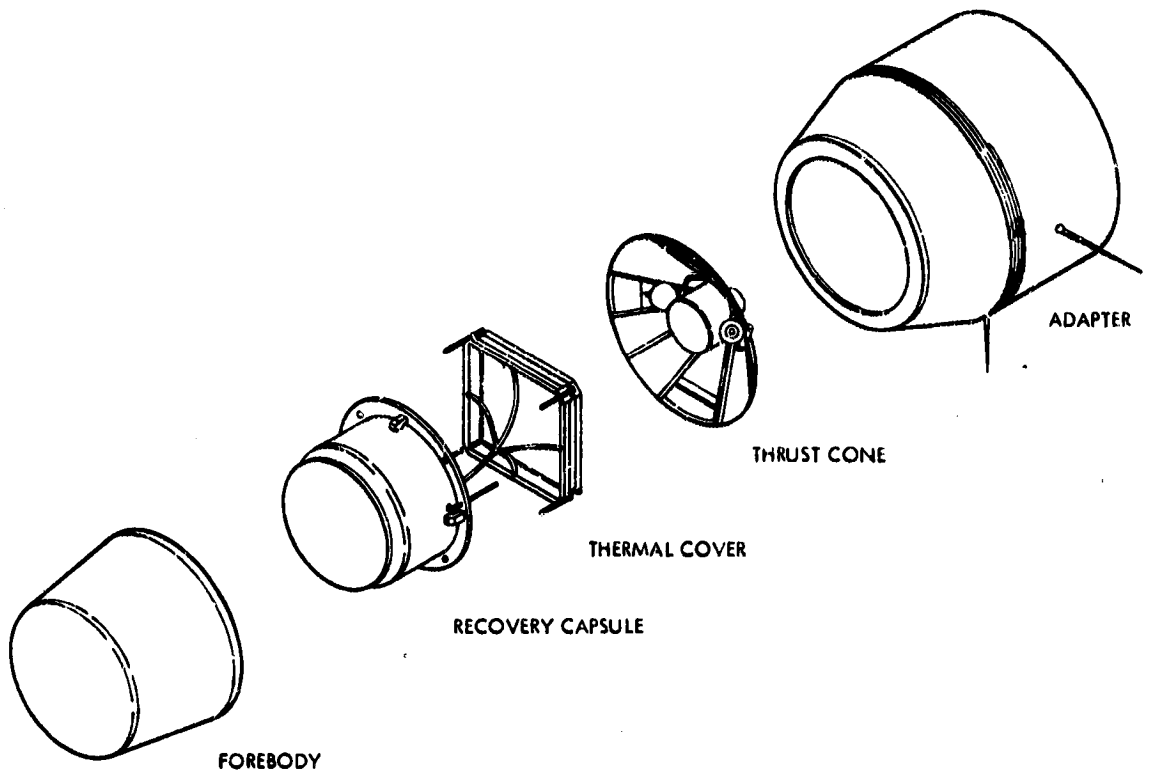


Fig. 1. Biosatellite spacecraft—exploded view

deorbit attitude achieved in all three axes, the reentry vehicle can separate from the adapter section, and spin up and fire the retrorocket to initiate the reentry sequence.

C. Experimental Conditions and Environment

To maintain the simplest launch vehicle mechanical interface, the Pace/Rho experiment is mounted on a thermal control plate. The return coolant from the fuel cell flowing through this plate maintains the experiment temperature at a design temperature range of +42 to +85°F, with a maximum rate change of 1°F/min. The experiment package is attached to this plate by four bolts. The remaining five sides of the package are enclosed in superinsulation consisting of 28 layers of alminized Mylar film. The total emissivity of this enclosure is 0.01, which, in essence, says that the total heat flux generated within the Pace/Rho unit will be conducted away by the thermal control plate. Other requirements are shown in Tables 1 and 2. Table 3 presents a summary of the instrument components.

The experiment package must be capable of meeting various environmental test conditions prior to being accepted as flight-worthy equipment. Static accelerations are the environmental tests performed to simulate the launch conditions. This test consists of applying 12.5 g parallel to the thrust axis and 3 g in the other orthogonal axes. The various levels of vibration can best be defined as a sweeping sinusoidal acceleration between 10 and 2000 Hz. The range of from 14 to 40 Hz is at 5 rms g, increasing in amplitude between 40 and 62 Hz to a level of 12 g and remaining at 12 g from 62 to 2000 Hz. A random noise test with white Gaussian acceleration of 19.4 g total rms is required. Flight hardware is tested at 60% of these values. The experiment is subjected to an acceleration pulse (shock) of 50 g peak and duration of 1 ms This pulse is applied three times along each of the orthogonal axes. In addition, the package is temperature-cycled several times between +40 and +125°F. It is subjected to a thermal vacuum test of 72 h as a part of the total testing, and is operated for 300 cycles, less the number of test cycles already encountered in the earlier portion of the test program as a part of the endurance test. The thermal vacuum testing subjects the package to 10^{-5} torr for 24-h. The instrument case is allowed a maximum leak rate of 0.6 scc/min.

Upon completion of all testing, the instrument is inspected, operated, and subjected to the various applicable operational acceptance test procedures required to verify that the unit is in an acceptable operating condition.

D. Experiment Controls

During flight, the instrument is required to perform a daily calibration of itself with an internally supplied

Table 1. Experiment interface conditions

Mechanical	
Volume	330 in.^{3}
Shape	5.5 × 6.0 × 10.0 in.
Weight	15.0 lb
Mounting	Four-point attachment to thermal control surface
Connectors	Two electrical, two fluid, one gaseous
Electrical	
Power	6.5 W avg; 12 W peak
Voltage	26 ± 5 Vdc from fuel cell
Signals	Isolated from fuel cell and each other
Timing commands	1 min, 5 min, 1 h, and 24 h
Event commands	Urine delivery when urine is delivered
Telemetry command	ON signal when communicating with the ground station
Fluid	
Urine transfer	Fail safe delivery through unit
Urine volume	10 ml aliquots, bubble-free
Reagents	All self-contained within unit
Reagent refill	Through septum accessible from outside the spacecraft
Gas	
Nitrogen	Less than 0.1 lb/month for makeup volume
Limitations	Fail-safe N_2 shutoff of supply
Thermal	
Range internal	42 to 85°F
Range external	−30 to +100°F
Insulation	28 layers aluminized Mylar, super insulation $E < 0.01$
Data System	
Readout	Synchronous with telemetry commutator scan; 12½ bits/s
Words	9—real time—engineering data 7—stored for nondestructive readout
Format	7 bits per stored word 7 time samples per real-time (analog) word

calibration solution that establishes a known operating point within the analyzers and throughout the electronics and data handling system. This calibration point is compared with data gathered from standard laboratory analyses of the same calibration solutions, on the ground, at the same time intervals. Deviations between the ground and the in-flight analyses of the calibration fluid are used to modify the calibration curves of the instrument and/or to perform in-flight troubleshooting. The ground controls are maintained at a temperature profile similar to that actually experienced in the flight units. The temperature profile is updated four times a day to simulate the temperature effects experienced by the fluids in the experiment package. All of the solutions used for in-flight analyses are maintained and used during the ground-control analyses to establish a base line.

E. Experiment Chemistry — Urinary Calcium Assay

The calcium concentration is measured by fluorometry. The calcium ion combines with 2, 4-bis-[N'N-di-(carboxymethyl)aminomethyl] fluorescein (calcein) to form a fluorescent complex. The calcium analysis of primate urine is performed by adding a measured aliquot of the urine to a solution of calcein in 0.45 N KOH and 0.30 M potassium citrate. Calcein possesses little fluorescence in 0.45 N KOH, and fluorescence is generated only by calcium, barium, or strontium. Barium and strontium cannot be distinguished from calcium in this reaction; however, their presence in any natural urine was found to be negligible. Other ions present in urine, such as potassium, sodium, magnesium, and chloride do not interfere in this pH range, nor does protein. Both mono- and di-calcium complexes are formed, with the latter being the fluorescent species. Because of the nature of this chemical reaction, the calibration curve is logrithmic over the range of interest. Since this reaction occurs between the calcium ion and the dye, the calcium ion should be made available to the dye by preventing its precipitation from solution as either organic or inorganic compounds. This assay is greatly improved in this aspect by adding potassium citrate to the reagent. Fluorescence is optimally excited by a light at 490 mμ wavelength, with the emission detected at right angles to the primary beam at 520 mμ.

The range of calcium analysis in the biosatellite experiment is from 0.5 to 20 mM/l of primate urine. To cover such a wide range of calcium concentration, the ratio of the urine sample to the reagent concentration is first selected to provide a minimum dynamic range of 0.5 to 3 mM concentration of calcium. If the analyzer determines that the concentration of calcium is in excess of 3 mM, it performs a second analysis by diluting an aliquot of the fluorescent mixture with fresh reagent. The ratio of the mixture aliquot to the reagent is such that a minimum dynamic range of 3 to 20 mM concentration of

Table 2. Pace/Rho fluid storage-bag requirements

Type of test	No. Tests	Amount/sample, ml	Samples/test	Cr and Cr	Volume, ml	10% Pad, ml	Total volume required, ml
Calcium							
Calibrate	30	0.0133	1		3.99	0.40	4.39
Calcein	150	0.0701	2		21.03	2.10	23.13
0.12N HCl	150	0.23	2		69.00	6.90	75.90
Creatine–Creatinine							
Calibrate	30	0.0133	1	X2	7.98	0.80	8.78
H_2SO_4	150	0.0701	1	X2	21.03	2.10	23.13
Picric Acid	150	0.23	3	X2	103.50	10.35	113.85
NaOH	150	0.0367	1	X2	110.10	11.01	121.11
Total fluids					336.63	+ 33.66	= 370.29

Assumptions:

1. Waste pump displac s 0.23 ml stroke.
2. Test cell volume (0.109-in. ID × 0.50-in. long) = 0.0834 ml (20 turns).
3. Calibrate and urine sample volumes = 0.0133 ml (3.2 turns).
4. Calcium test is always double dilution.
5. Fluids needed for 30 days at 4 urine and 1 calibration per day.
6. Fluid storage containers to have 10% volume reserve.
7. Creatine and creatinine fluid requirements are identical.
8. Picric acid is used as the creatine-creatinine rinse solution.
9. HCl is used as the calcium rinse solution.

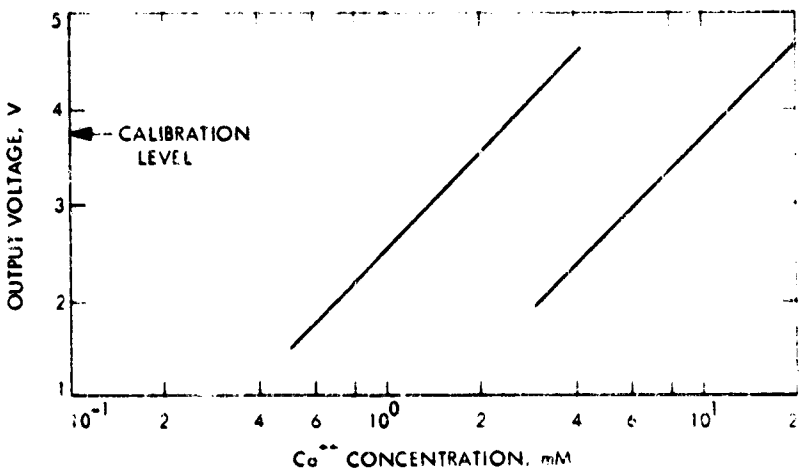


Fig. 2. Calcium calibration

calcium is provided. The calibration curve is shown in Fig. 2.

The method is not too precise at the 0.5-mM concentration level. The reproducibility and precision of measurement increases with increasing concentration. At a mean value of 1-mM calcium, a 3% deviation is noted. This deviation increases to 8% as the concentration is decreased to 0.5 mM. The analyses of 2- and 3-mM calcium, however, indicate a relatively small value of percent deviation (1 to 1.5%), and their confidence level is well within 95%. The experimental results of the recoveries obtained with various amounts of calcium added to

Table 3. Instrument component summary

Components	Quantity
Electronic discrete parts	880
Electronic integrated circuits	402
Motors, dc	8
Fluid pumps	2
Valves, rotary and check	10
Switches, mechanical	17
Light bulbs	4
Temperature sensors	5
Optical systems	4
Fluids (H_2SO_4, HCl, NaOH, etc.)	7
Printed circuit boards	34
Welded modules	9
Stick modules	23
Gear trains	8

primate urines indicate that the recovery is mostly over 95% and suggest the method to be highly accurate.

F. Experiment Chemistry — Urinery Creatinine and Creatine Assay

The creatinine concentration in primate urine is determined in an aliquot mixture of the urine with an alkaline picrate solution (Jaffe reaction) by colorimetry. Then creatine is determined by first converting it to creatinine by heating in an acid (H_2SO_4) solution at 100°C for 25 minutes. This solution now contains the original creatinine plus the creatine hydrolyzed to creatinine. This solution is then assayed for its total creatinine concentration. This value of creatinine represents the original creatinine plus the converted creatine (multiplied by the conversion efficiency of the conversion reaction). The converted creatinine is then calculated by subtracting the value of the original creatinine value determined by a similar assay performed without the heating (hydrolysis) step. The concentration of creatinine is measured by measuring the optical density of the test solution after the Jaffe reaction is completed. The difference in the optical density of the reaction products obtained for creatinine with and without the heating step is attributed to the presence of the urinary creatine. The reagent solutions used consist of 4N sulfuric acid, 1.5N sodium hydroxide, and 0.03 M picric acid.

A urine sample is analyzed by mixing it first with sulfuric acid in a ratio of 1 to 5.4, and then by adding 17.6 parts of sodium hydroxide and 16 parts of picric acid. After mixing, the absorbance of light is measured at 490 mμ. The range of creatinine analysis in the Biosatellite experiment is from 3 to 25 mM and the creatine from 3 to 20 mM.

Among the variables involved in the Jaffe reaction are concentration of picric acid, temperature, and pH of the reaction mixture. The optical density of the reaction product was found to be sensitive to the picric acid concentration for a picric acid-to-creatinine ratio less than 4. This effect is avoided in the present method by keeping the picric acid to creatinine ratio equal to, or greater than, 8. The developed color is then independent of the picric acid concentration for all creatinine concentrations up to 60 mM. The temperature during color development is immaterial between 15 and 35°C, but the temperature of the solution while it is being read is important. As temperature is increased, the absorbances of alkaline-picrate and alkaline-creatinine-picrate both increase, but not proportionately. Approximately a 0.5% increase in absorbance for each degree centigrade increase is observed over the range of 32 to 37°C. The color intensity of alkaline–creatinine–picrate increases with decreasing pH, whereas that of alkaline–picrate decreases with decreasing pH.

The conversion of creatine to creatinine is accomplished by hydrolysis in strong sulfuric acid. The strength of the acid necessary to bring about conversion depends upon the period of heating and the temperature. For a 25-min heating at 100°C in 4N sulfuric acid, the quantity of creatine converted to creatinine is more than 95%. If the strength of the acid added is decreased to 2N, the conversion will only be approximately 80 to 85%. The conversion of creatine to creatinine, using 4N sulfuric acid, was found to be insensitive to temperatures over a range from 95 to 121°C. The calibration curve is shown in Fig. 3.

The overall precision of the method for the creatinine concentration range is approximately ±5% and, except for concentrations less than approximately 6 mM, ±3% can be routinely obtained. For creatine, which is normally present in urine in much smaller amounts than creatinine, the precision is much less. The recoveries of added creatinine or creatine from primate urines are mostly between 93 and 95%; this indicates that the method is reasonably accurate.

G. Experiment Implementation

Consider the single-step chemical analysis used to assay calcium by using calcein reagent. (It is assumed that the various solutions are pre-mixed and of known

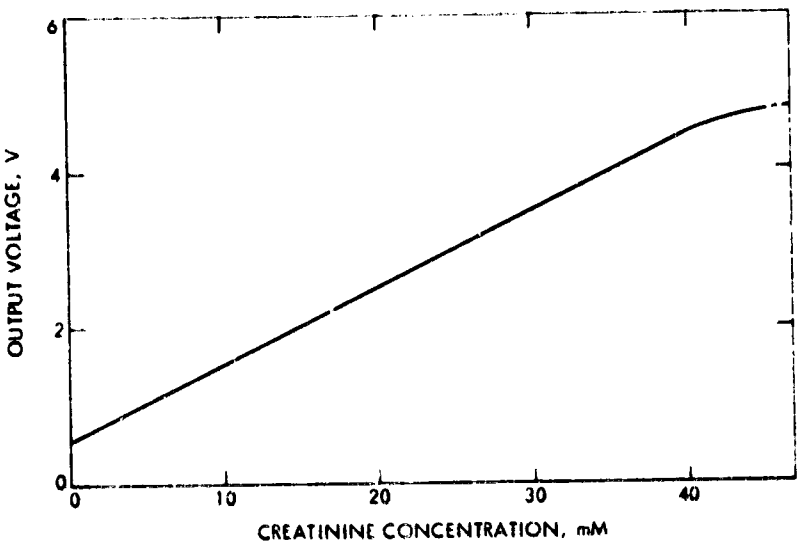


Fig. 3. Creatinine calibration

strength and that the readout instrument is suitably calibrated.) In the conventional laboratory, the specific details in performing routine steps, such as metering, mixing, heating, timing, standardizing solutions against known solutions, rinsing, moving, or dilution solutions, etc., are taken for granted when the experimenter says: "Mix metered solutions of A and B, then quantitatively determine the fluorescence of the reaction products in a fluorometer." The technician, in performing the typical laboratory analysis, must first pick up the test tube, measure a specific volume of urine into the test tube with a pipette, then add a known volume of calcein reagent with another pipette. He must then agitate the two solutions by shaking the test tube. At this point, the reaction is complete; however, to assay the reaction, he must first place a test tube containing stock solution (calcein) into a fluorometer and measure its background fluorescence. The sample solution is then placed in the fluorometer and its fluorescence read. After taking the difference of these two readings and comparing to the calibration curve, the calcium concentration present in the sample would then be known. After determining the concentration, the technician then empties the tubes into a waste container, washes, rinses, and returns them to a drying rack for use in succeeding analyses.

In automating these analyses for flight, however, the instrument designer must consider all of the details in the sequential and parallel steps necessary to implement the analysis (see Appendix A for the sequence of steps used in this experiment). The engineer must evaluate the thermal exchange requirements of the experiment and make suitable allowances in the thermal controller design to maintain the proper temperature control with adequate safety margins. Other factors must also be considered. For example, the temperature stability versus time of each of the solutions must be known to allow selection of the proper temperature control of the stored fluids. The temperature sensitivity and time dependency of the reaction must be known to permit proper design of the circuits controlling the test and reference cell temperatures during the analysis and data readout. The dead volume of the analyzer and associated plumbing must be known, and its effects upon the analysis accuracy and repeatability must be determined.

H. Unit Configuration

The instrument is a 15-lb, 330-in.^{3} package located in the adapter section of the vehicle. The instruments' major components are shown in Appendix B. The experiment is required to carry all of the fluids, a fluid-sampling system for collecting the urine sample, the creatine–creatinine analyzer, calcium analyzer, suitable logic sequence networks, a power converter which converts raw power from a hydrogen–oxygen fuel cell contained in the adapter section, and a data-handling system. A view of a completed flight instrument is shown in Fig. 4.

This figure shows the fluid storage containers, including collapsible silastic rubber bags storing the various calibration, rinse, and reagents needed to perform the analysis of calcium, and a supply of creatine and creatinine for flight missions of 30 days. The urine sample accumulator system shown in Fig. 4 acquires, stores, and delivers urine to the analyzers upon command. The creatine–creatinine analysis is performed within the creatine–creatinine analyzer block and electronic chassis subsystem, which contains the test tube, fluid-metering equipment, thermal control heaters and electronics, colorimeter electronics, light source, and filters. Components in the calcium analyzer are functionally the same as in the creatine–creatinine analyzer. Other views are presented in Appendix C.

I. Analyzer Description

At the inception of the program, the realization that all fluids must be carried within the experiment package for the performance of all analyses dictated that the analyzed sample must be quite small. To do this required the utilization of existing techniques, as well as the development of new methods for metering, mixing, and optical readout of very small chemical samples. This resulted in a test cell of 83-μl volume. Since the test cell must be reusable, it must be adequately rinsed after each analysis. As a result, the rinse solution is the single largest fluid volume required.

Because colorimetric and fluorometric analyses are required, it was desirable to make the main analyzer blocks interchangeable as far as possible. As a result, the unused detector openings in the block are utilized as viewing ports to observe the proper functioning of the light source, manipulation of the fluids by the test cell piston, and to monitor the presence of bubbles.

The analysis is performed in a Pyrex glass test cell 0.109-in. inside diameter by 0.500-in. long. The cell is one of several elements comprising the optical system. Central to the optical system is a miniature, tungsten filament light source (Pinlite 60-25). Excitation of the

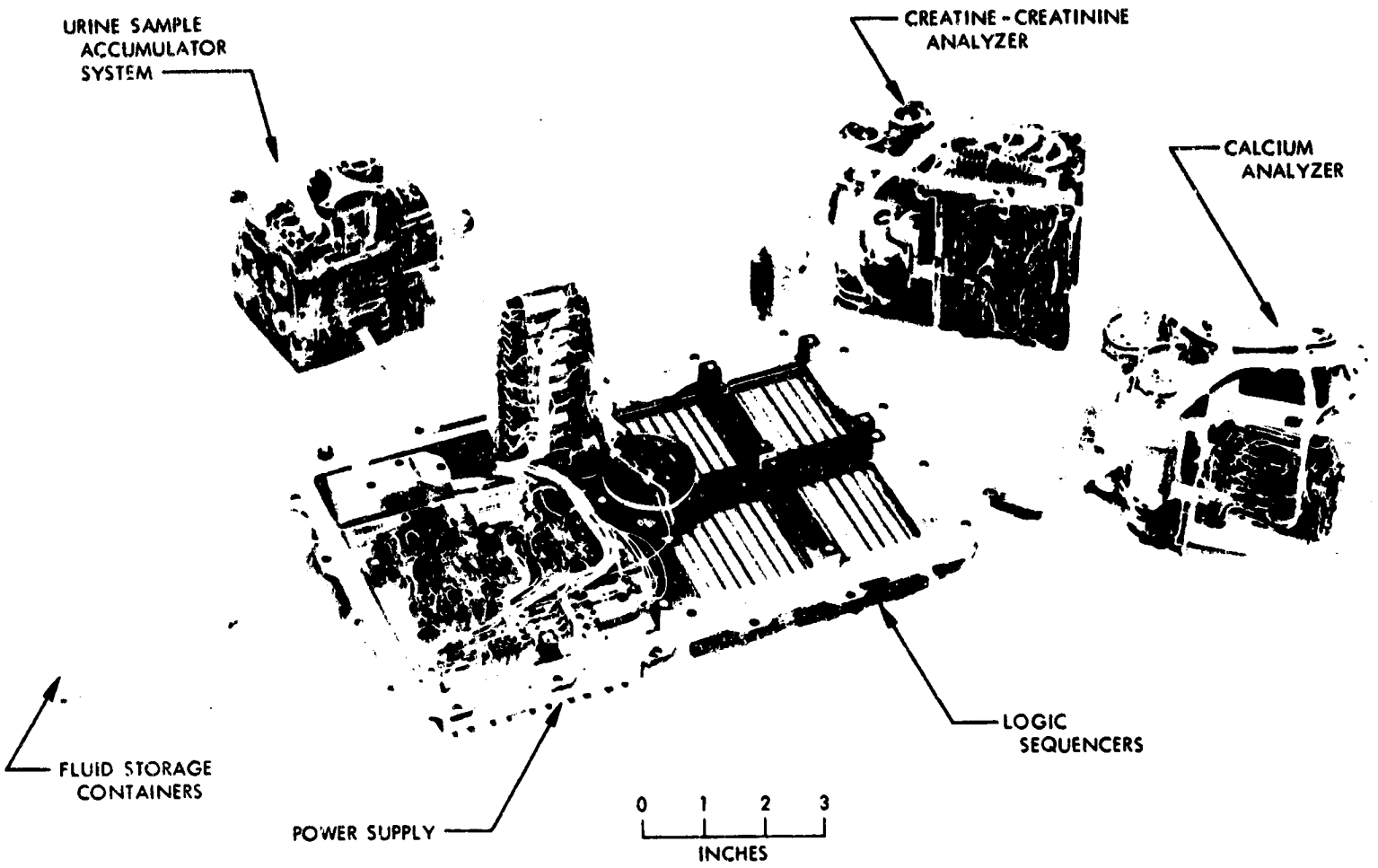


Fig. 4. Components surrounding the power converter and sequencer electronics chassis

test and reference cells is provided by filtering this illumination through Corning glass filters tailored to meet the spectral bandwidth and transmission characteristics needed for the specific analysis. The light transmitted through the cells is then detected by the photo detectors (Clairex 903N). For fluorescence measurements, the detectors look at the test and reference cells through band-limited filters designed to attenuate the excitation and transmit the fluorescence emissions from the cells. The impedances of the test and reference detectors are compared in an operational amplifier feedback circuit. The colorimeter (creatine–creatinine) circuit is a ratio configuration whereas the fluorimeter (calcium) is a difference configuration. These configurations were chosen to maximize the data range and yet provide adequate accuracies in the presence of optical and electronic variations. The relative detector drift is minimized since the test and reference cells have thermal control heaters located to maintain a symmetrical heat flow through the respective detectors.

Ideally, a mechanically or optically switched dual-beam colorimeter or fluorimeter with a single excitation source, filter set, and detector would form a superior system. The existing system constraints prevented use of this technique. The detectors are picked for maximum sensitivity in the 490- to 520-mμ range and a minimum change in sensitivity versus temperature from 40 to 100°F. From pre-selected detectors, matched pairs are assembled for optimum temperature versus resistance tracking properties. The amplifiers measure typical impedance variations from 250 to 50 MΩ.

To improve reliability and minimize the logic and sequencing requirements, the calcium analysis and the creatine–creatinine analyses are performed in individual analyzers. The analyzer test cell is instrumented to provide temperature control during the analysis and readout of the data. In the creatine–creatinine analyzer, the test cell is also instrumented to provide a high-temperature range to effect conversion of creatine to creatinine. In

addition, each analyzer is instrumented to allow accurate metering of solutions. The various solutions are brought to the respective analyzer test cell by internal porting in each of two rotary valves mounted within the analyzer (see Fig. B-11, of Appendix B). The analysis philosophy required a design that minimized dead volume, and hence decreased the possibility of cross-contamination of the various solutions. The test cell contains 83 μl of solution. Mixing such a small volume of fluid presents an interesting challenge. The typical method of mixing solutions by mechanical agitation is not practical in this package configuration because of the small sample size.

Therefore, the mixing is done within an enclosed flexible container. This container must be very close to the test cell to minimize the dead volume between the mixing container and test cell. The fluid remaining in this dead volume represents a contaminant in succeeding analyses. Therefore, the sequencer is programmed to leave rinse solution here prior to the next analysis. To achieve good mixing, it is usually advantageous to strongly agitate the solutions. "Stirring" of the unmixed reagents contained in the test cell is not easily implemented. The only practical solution is the installation of a small flexible diaphragm within a cavity in one of the rotary valves. The diaphragm is inflated and deflated by manipulation of the fluid from the test cell through the valve porting and into the mixing cavity a number of times. The physical configuration of the valve and cavity creates turbulence and hence mixing. During ground testing, it is estimated that mixing is 90% complete after the small volume of fluid is manipulated in and out of the mix chamber at least seven times. This percentage should be higher during the flight mission where density gradients within the fluids are no longer effective in keeping the fluids separated because of the zero-g field.

The mechanical development of this particular mixing method posed some interesting technical problems. For the valve to have a low-rotational torque, it is necessary that the interface between the rotor and stator be very circular and smooth. The sliding surfaces must be coated with a material possessing a low coefficient of friction which is inert to the various chemicals used. To achieve this, the valve rotor surface is manufactured from Teflon. The stator of the valve, which also becomes the body of the analyzer, is made from Kel-F. To maintain rotor dimensional stability, the rotor must be supported internally with a material more rigid than Teflon, which will cold-flow under stress. This support member is made of Kel-F. The Kel-F, in turn, must support the small silastic rubber diaphragm covering the mixing chamber. To prevent the Teflon sleeve of the rotor from collapsing upon the diaphragm, the diaphragm is backed up with a small bathtub-like configuration of titanium, which also supports the Teflon sleeve. The valve, once assembled, is then drilled with several interconnecting ports, which form the internal logic of the valve. The major technological problem was the finding of suitable cementing agents which would cement Kel-F to Teflon, Kel-F to silastic rubber, silastic rubber to titanium, and Teflon to titanium. Three different types of cements were used. To achieve the uniformity required for long-term flexibility of the silastic rubber diaphragm, it was necessary to mold a very small O-ring as an integral part of the diaphragm. This O-ring is 0.010 in. in diameter and mates with a similar groove in the Kel-F rotor at the time of assembly. Figure 5 shows an exploded view of this valve and the internal mixing diaphragm.

The surface finish required on the Teflon rotor and Kel-F valve body is less than 5-μin. roughness and a circularity of 50 μin. on a $\frac{3}{8}$-in.-diameter valve bore.

J. Urine Sample Acquisition System

The operational sequence of the urine sampling system is given in Appendix B, Figs. B-1 and B-3 through B-7. All urine is to be sampled and a portion stored in a common reservoir during each 6-h period. The fluid-handling system must possess certain characteristics. It must be fail-safe. Failure of any element within the system must not cause failure of the spacecraft, or any of the other experiments or systems within the spacecraft. To this end, all urine flows through the fluid-handling block through a sleeve filter from which the urine sample is taken. After it has passed through the sleeve filter, the urine then passes through a back-pressure regulator, which is a large diaphragm opening only when the fluid-line pressure is greater than the experiment package atmospheric pressure. The urine and waste products then leave the experiment package through the back-pressure regulator waste exhaust manifold connected by plumbing to the metabolic waste container, located in the adapter portion of the vehicle. Between the hour and 10 min after the hour, the reentry vehicle urine accumulator is commanded to empty its contents through the urine transport system, the JPL fluid-handling block, and back-pressure regulator, to the waste container. Urine is displaced through the system in 10-ml aliquots by a metering pump contained in the reentry vehicle. The pump actuates the fluid-handling block accumulator, causing it to remove simultaneously 1 ml of urine sample and to replace it

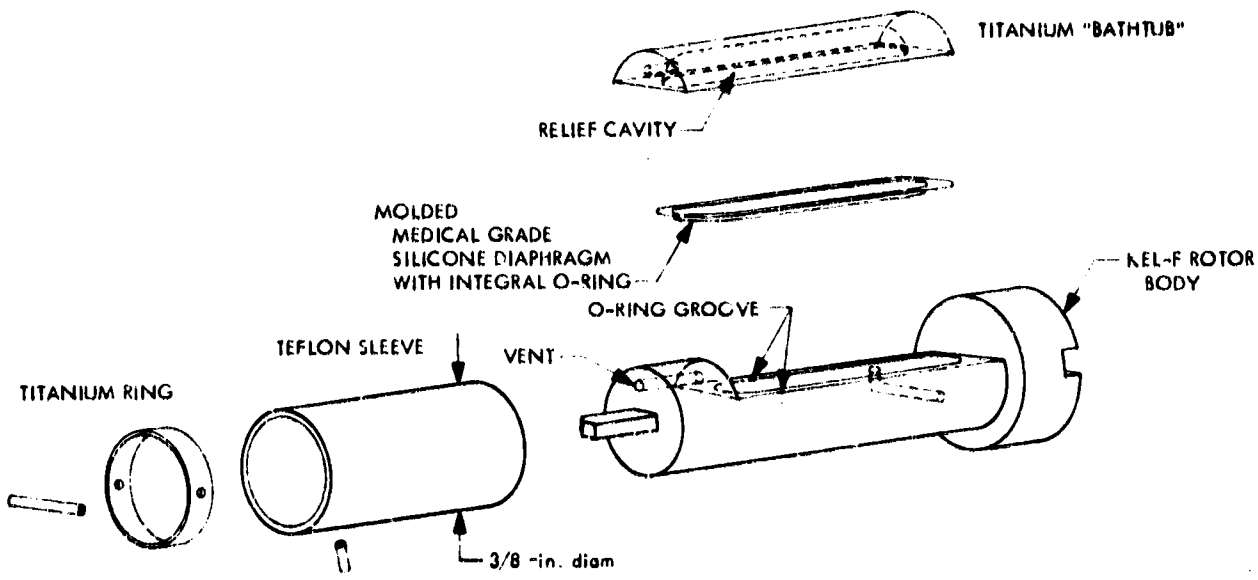


Fig. 5. Analyzer rotary valve (V2) with mixing chamber

with 1 ml of waste products into the line leading to the metabolic waste container. Urine sampling occurs while the General Electric (GE) pump is acquiring the next 10-ml sample for delivery. When the urine accumulator in the reentry vehicle is empty, no additional samples are delivered. The fluid-handling block can store fifteen 1-ml urine samples. These samples are accumulated during a 6-h period (see Fig. B-1, Appendix B). At 10 min past the hours of 3, 9, 15, and 21, the fluid-handling block accumulator is commanded to dump its contents through the analyzers and back through a check valve into the sleeve filter, thus back-flushing any debris accumulated on the sleeve filter during the previous 6 h. From there, the urine flows through the path marked "short circuit" to the back side of the accumulator pump. This is done to maintain a constant-volume fluid-handling system. The contents of the back side of the accumulator pump will be metered into the waste line during the next 6 h as the new 1-ml urine samples are accumulated. To meter the calibration and rinse solutions from their storage containers through the analyzers and into the waste system, an auxiliary path is provided in the fluid-handling block. This is accomplished by actuating a waste pump whenever fluid transfer is required. Flow direction is maintained by check valves 4 and 5. This pump meters approximately 0.23 ml of solution at each actuation. This is the minimum sample volume required to purge the analyzers and yet leave an adequate sample for subsequent analysis.

Check valves 1 and 2 bracket the accumulator inlet and outlet. They are oriented to allow flow of the urine sample through the screen filter and into the accumulator through check valve 1, and to prevent any back flow of fluid from the analyzers through check valve 2. During the delivery cycle of the urine sample to the analyzers, check valve 1 is blocked and check valve 2 allows the urine sample to pass through the analyzers and check valve 3 to backflush the screen filter. Check valve 3 is installed to prevent the waste pump from moving fluid around within the fluid-handling block. This valve directs the waste pump driving force directly through the analyzers and to the fluid storage bags, thus transfering these fluids, when required, to the proper analyzer.

The fluid-handling block is made of lucite. The metals in contact with the solutions are made from 303 stainless steel. Tests have shown these materials to be best suited for the various fluids encountered. Rubber products are generally Viton B, although a number of neoprene O-rings are utilized in areas where there is non-active contact with the solutions.

The fluid-handling block contains two dc electric motors and their gear trains, five check valves, a screen filter, a back-pressure regulator, and the internal plumbing needed to carry out the functional acquisition and delivery of the urine sample. In addition, this block is the support member for a battery, two pressure switches used in the nitrogen pressurization system for the package, five switches used in monitoring pump displacement locations, and various other electronic components used in housekeeping functions. Urine is delivered to the analyzers and returned along with the waste products through two manifolds. These manifolds serve as a transition point between the fluorinated ethylene propylene

(FEP) tubing, connected to the analyzer, and the internal plumbing in the block. Each manifold has three ports. Each analyzer is connected to a port. The third port is attached to the fluid refill access assembly located on the base of the package. This allows removal of a representative urine sample comparable to that analyzed in the analyzers. This sample is analyzed by conventional techniques as a check on analyzer function.

One of the pumps in the fluid-handling block is check valve 4 which, in reality, is a combination piston and sliding sleeve valve (see Appendix B, Fig. B-6). A pin on the piston rod contacts the sleeve during the forward stroke of the piston. At this point, the sleeve and piston cap are not in contact. The sleeve, being hollow, allows fluid to flow freely through the piston as the piston moves forward. On the return stroke of the piston, the rubber cap at the end of the piston rod is pulled into the sleeve and seals the sleeve to the piston head. O-rings seal the sleeve to the cylinder and, as the piston rod moves back, check valve 4 is closed. The fluid trapped on the downstream side of this check valve is forced to flow through check valve 5, which is of a standard diaphragm construction. As the cycle is repeated, fluid will be transported through the pump and discharged as waste material. This pump is similar to the water well hand-operated pump found on rural farms.

An innovation brought on by the system requirements is the backflushing of the sleeve filter. Backflushing is performed at the end of each 6-h accumulation period, as previously described. The purpose of backflushing is to remove any debris which may have collected on the screen filter during the preceding 6 h of sample accumulation. It is recognized that there will be some partial obstruction caused by material being permanently affixed to the sleeve filter; however, it is also recognized that the periodic backflushing action will result in an equilibrium condition wherein the screen will remain open to the passage of the urine sample to the accumulator when required. This is shown in Appendix B, Fig. B-5.

The purpose of the back-pressure regulator is to maintain the fluid pressure in the system at the package pressure and yet allow any additional volumetric increase in fluid to pass into the waste container with a minimum energy expenditure. In reality, this back-pressure regulator opens with approximately 3 in. of water pressure difference across the diaphragm.

K. Fluid Requirements

Thirty days of unattended operation, at the rate of five analyses per day on each of three compounds, means that the experiment must store enough fluids for more than 450 analyses. A contingency volume of fluid is needed for preflight testing, calibration, and in-flight evaporation losses. The space available on the spacecraft is limited to 330 $in.^3$ for the total Pace/Rho experiment. Preliminary estimates divided the experiment into the five subsystems shown in Fig. 4 and Appendix A. The fluid storage module is 3 in. by 4½ in. by 3½ in., or 47 $in.^3$ (774 ml). The assignment of the available volume for active fluid storage is given in Table 2. The package configuration is shown in Figs. C-1 and C-2, Appendix C, and Fig. B-9, Appendix B.

It may be shown that a total volume of approximately 370 ml is required, which includes a 10% contingency volume for such things as residual left in the bags at the end of the mission, unequal metering of the waste pump, and general evaporation losses through the materials of the bags. Each of these fluids is stored in a separate flexible container. The various containers are then stacked to form a total assembly. To refill the containers just prior to the mission launch, each container has a filling line attached to the fluid refill assembly, mounted on the base of the package. This assembly is accessible through an opening in the vehicle's skin. The other line in each bag is directed to the appropriate analyzer unit. The bags themselves are made of FEP. The line was selected for its chemical resistance and lack of fluid permeability. The bags are molded in half shells, which are then heat-sealed together along with the tubes for refill and delivery of solution to the analyzers. The final molded assembly is then a flat, flexible bag which collapses as fluid is withdrawn. Each bag is conformally supported during the launch vibration environment by resting within a machined lucite retainer. The complete assembly is then mounted on the main base plate by means of six bolts.

The fluid refill septum is designed to meet the interface of accessibility from the exterior of the spacecraft and yet provide a means of maintaining the pressure integrity of the package during flight, the individual integrity of each fluid container, a means for nitrogen pressure equilization during testing, and urine sampling from the fluid-handling block. The septum is a solid metal block with a series of holes in which a suitable silastic rubber O-ring septum has been molded. Platinum tubes

attached to the various flexible lines leading to the fluid storage bags or fluid-handling block are mounted on the interior side of the assembly. To prevent electrolysis and corrosion, each platinum tube extends through the body of the assembly and is in direct contact with the septum. To provide additional assurance that the septum will not leak during the flight, a cap is screwed down over the exterior of the body, thus compressing the septum and providing additional forces for sealing off any small leakage path that may have been left as the result of a needle puncturing the septum to insert fluid or take urine samples or just the internal pressure of the package during testing.

L. Logic Sequencing

The logic sequencer is the command center of the instrument. Its function is to carry out in a well-defined, orderly manner all of those series and parallel operations required to complete the analyses as described in Appendix A. The block diagrams of the various subsystems and the total system are presented in Appendix D.

To gain an understanding of the scheme for implementing these sequence steps, the following description should be used with Fig. 6. This diagram outlines the tasks performed by this digital control system. As shown in Fig. 6, the Experiment Timer is the central command post of the urinalysis experiment. It receives 24-h and 1-h clock pulses from the spacecraft and generates sequence start commands for the two analyzers at 0, 3, 9, 15, and 21 hours. Immediately preceeding each sequence start command, the Experiment Timer receives information from the Urine Sampler Control informing the Experiment Timer that enough urine has been collected over the previous 6 h for an analysis. This information is processed and passed on to the calcium and creatine–creatinine sequencers. If there is insufficient urine available, then the Experiment Timer will instruct the sequencers to perform a calibrate sequence. At the 0 h, the sequencers will be programmed to do a calibrate sequence regardless of urine status. When a sequence (calcium or creatine–creatinine) has been initiated, the Experiment Timer is then inhibited from sending further start commands until each sequence is completed. This is done so that the sequencers cannot be interrupted.

The sequencers, once initiated, provide the proper drive commands to position valves, fill and empty the test cell, cycle the waste pump, and control the data handling system that are required to make the scientific measurement. Because the calcium and the creatine–creatinine sequences are similar, only the function of the Calcium Sequencer will be discussed.

The principle is to first set the two valves (V1 and V2) to particular positions. When the valves are in position, several events could be initiated depending on the position of the valves. If the test cell microsyringe plunger is then turned on to fill the test cell, then, when the test cell is full (signifying completion of this event), the valves, through a feedback path, are re-positioned for the next event which may be to turn on the Waste Pump. Following completion of this event, the valves are again re-positioned, etc., until the sequence is completed.

The following is a discussion of the sequence of operations necessary to perform a calcium analysis (see Appendixes A and D for an outline of the sequential steps).

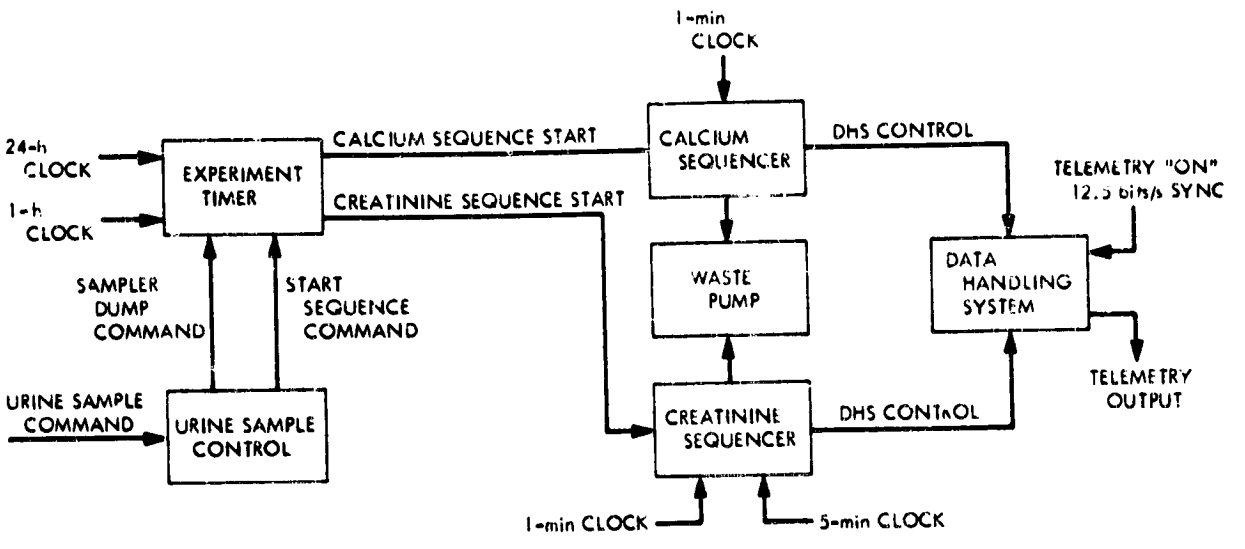


Fig. 6. Functional block diagram

The Timer in Fig. D-2 receives timing pulses from the spacecraft. It is assumed that the 24-h counter and test time decoder has just been updated to a count of 3 h. A level change is then provided to the 5–10 min Delay Logic. Two additional 5-min pulses are received by the 5–10 min Delay Logic before a level change occurs at its output. This level change is routed to the Fluid Sampler Dump Control Logic which commands the Fluid Sampler Drive to empty the accumulated urine through the two analyzers (see Appendix A for valves in a *Urine/V*$_1$*-Waste* position for calcium and creatine–creatinine). The Dump Control Logic then sends a command *Accumulator Empty to 1 cc* to the Creatine–Creatinine Start Command Logic which, in turn, starts the Creatinine Sequence. Once started, a *Creatine–Creatinine Sequence Start Command* is routed to the Calcium Sequencer. The next 5-min clock pulse starts the calcium sequence shown in Fig. D-3 by providing *Sequence Start Command VC1* to the Valve Selector Reset Logic.

This logic is a programmer consisting of a three-stage binary counter and seven decoder gates with only one decoder gate output being active for each stable state of the counter. One decoder gate is used for each valve change of valves 1 and 2. Therefore, with a three-bit counter, eight valve changes are allowed. The eighth valve change is used as a standby to open up the control loop and stop the sequence.

The VC1 command is received by the Valve Combination Selector Logic, which is really the programmer of the system because here the particular valve positions are actually selected (Fig. D-3). Decoder gate VC1 will put valve 1 at the urine position and valve 2 at the V1–Waste position. Since urine is already in the V1-V2 area, the waste pump is inhibited because a urine sample is already present. (The waste pump operates to bring a calibration solution into this region when VC1 is generated during a calibration sequence). The valves are driven in response to the decoder gate commands. One side of the valve drive motor is tied to +4.5-V dc motor supply. The other side is tied to the metal disc serving as the switch rotor. When a transistor connected to a switch position is turned on, a ground return is provided for the motor and the valve-switch combination rotates. When the notch in the switch rotor breaks the collector of the turned-on transistor, the motor stops because of loss of a ground return. Thus, the valve can be rotated to any position simply by turning on the transistor whose collector is connected to that position. It is not necessary to remove the drive current to the transistor once the position is selected. An emitter follower is used to provide current gain between the transistor and the NOR gates. At this point, the UR/V1–Waste enables the Micro-Syringe Fill Control Logic to start the motor driving the syringe to fill it with a urine sample. The volume of the sample is determined by the Revolution Count Logic. Starting with an empty test cell, revolutions of the gear drive to the plunger are counted in a three-stage binary counter (the Revolution Count Logic). Input to the counter is from a revolution count switch mounted on the microsyringe plunger gear drive assembly. To eliminate contact bounce from giving false counts, the switch is buffered with a flip-flop arrangement. The specified number of revolutions are sensed by NAND gate. The output of this gate goes positive (logical 0) when the prescribed number of counts has occurred. The counter is held in a pre-set condition until that point in the sequence is reached where revolutions are to be counted. At this point in the sequence, the Revolution Count Logic will count four revolutions and generate Valve Command 2 (VC2). This level change signals the Event Complete Logic, which in turn, increases the count in the Valve Combination Selector Logic to VC2. The VC2 tells valve 2 to move to the reagent position. Completion of this step initiates the Micro Syringe Fill Control Logic to fill the test cell an additional 16 turns to 20 turns total. The Fill Limit Switch signals the Event Complete Logic which updates the Valve Combination Selector Logic to VC3, the Blocked-Mix positions for V1 and V2.

This is the beginning of the mixing sequence. Once two solutions are brought into the test cell; they must be mixed. This is accomplished by emptying the entire contents of the test cell into a mixing chamber and back into the test cell. This process is repeated seven times to produce a homogeneous solution. The number of times the plunger actuates the full limit switch, when the test cell is full, is counted by the Mix Cycle Count Logic. The count pulse is obtained from the full limit switch one-shot. Contact bounce of the limit switch is eliminated by flip-flop B. The counter is also held in Preset until required for use in the Blocked/Mix position of V1 and V2.

When the mix sequence is completed, the micro syringe plunger drive motor is stopped by using the output of a NAND gate which senses completion of the seven mix cycles. At this point, the Second Dilution Determination Logic is asked whether the fluorescence exceeds a predetermined level. If so, this means that the concentration

of calcium exceeds the low range of the instrument, hence the mixture must be re-diluted with reagent to decrease the ratio of urine to reagent (calcein). To accomplish this, VC9 is initiated, causing the sequencer to follow the dilution sequence A (calcium) in Appendix A. This subroutine, when completed, should then have an output from the calcium data amplifier that is in range for this experiment. This is the point in the sequence where the analytical measurement is made. The Mix Terminate signal disconnects the preset of the DHS sequence counter (see Appendix D, Figs. D-6 through D-9), and it is allowed to count the 1-min clock pulses as shown in the diagram. The DHS command sequence proceeds as follows. The first NAND gate is actuated at the first 1-min clock pulse. This erases the old information stored in Register 1 of the Data Handling System. The second NAND gate provides drive to channel 1 of the Input Multiplexer and a word steer command for channel 1, so that the gated clock pulses will be counted by the correct register. In addition, this gate also provides a trigger to the encoder portion of the DHS. Finally, this gate erases the old information stored in register 2. Another NAND gate activates channel 2 of the input multiplexer, provides the proper word steer command, and generates the encoder trigger for word 2. Word 1 is the concentration of calcium and word 2 is the temperature of the test cell at the time of measurement. Next, another NAND gate is activated by the counter to signify the DHS sequence is complete. After the data are encoded, the DHS complete signal tells the Event Complete Logic to start the test cell cleanup operations of emptying the test cell, rinsing the plumbing, test cell, and mixing tub. Upon completion, the analyzer is left in a standby state of readiness to accept the next urine sample and start all over with the next analysis. The Creatinine-Creatine Sequence follows a series of interlocked steps similar to those described for the calcium analysis.

M. Data System Format

The actual urine concentration at the primate as a function of time may be determined if all of the following data are known (see curves in Appendix E):

(1) Primate urine transport system transfer function.

(2) Urine dilution factor -- the number of urine samples passed through the Pace/Rho experiment during each 6-h sampling period (see Table E-3).

(3) Urine sample factor – the number of urine samples accumulated in the Pace/Rho experiment during each 6-h sampling period (may be equal or less than item 2 above) (see Table E-3).

(4) Number of urine samples accumulated by the Pace/Rho unit each orbital pass.

(5) The number of urine samples passed through the Pace/Rho unit each orbital pass; these data are from the GE urine measurement counter.

(6) The telemetered data word for measurement concentration. (This is a seven-binary bit word.) There is one word for each chemical analysis (see Fig. E-1 and Table E-1).

(7) The conversion from the binary word to analog voltage data. This corresponds to the voltage output of the data amplifier (see Table G-1).

(8) The chemical concentration versus data amplifier analog voltage output calibration curve (see calibration curves for words 1, 4, and 6, and Figs. E-3, E-5, and E-6).

(9) Experiment test cell temperature (taken at the time the chemical concentration data is stored in the DHS). This is used to compensate the calibration curve in item (8) above (see calibration curves for words 2, 5, and 7, Figs. E-4 and E-7).

(10) The experiment temperature of the calibration solutions. This is used to establish long-term drift in the calibration solutions and to adjust the one-point calibration data received from the experiment (see Fig. E-9, word 13).

(11) High-range or low-range data bit for calcium calibration curve. This modifies item (8) above (see calibration data for word 3, 6th bit, Table E-3).

In addition, to recover the engineering data and make correction to the actual measured values, the following data are needed:

(12) Telemetered analog voltages (see calibration curves for words 9 through 16, Figs. E-7 and E-8, and Table E-2).

(13) Output isolator transfer function as a function of temperature (see Fig. E-2).

$$E_o = f(E_{in})(T)$$

(14) Temperature versus voltage calibration curves for bag temperature (see word 13, Fig. E-9).

The reduction of a science data word could use this format as follows (the numbers refer to the paragraph numbers listed above): Actual primate concentration at time t = (1) × (3) × (6) × (7) × (9) × $(11)^1$ × 12. In some cases, item $(3)_n$ may not be directly available and, therefore, must be derived by use of items (5), (4), and $(3)_n$. Item $(3)_n$ is the last available sample count of item (3) for the 6-h sampling period as follows:

$$(3)_6 = (3)_5 + |(5)_{(n-1)} - (5)_n| - (3)_{1\text{-}(n-1)}$$

where n = orbit number and the subscript number is the hour the experiment receives the sample

Similarly, the analog data may be reduced as follows:

Actual Analog Voltages (engineering)
= (12) × (13) × $(14)^2$

N. Miscellaneous Systems

To adequately support the instrument during the development, testing, calibration, and on-line flight operations, two additional pieces of equipment are required. One piece of equipment is the AGE (Auxiliary Ground Equipment) console which is capable of simulating all of the required active spacecraft functions. These functions include timing commands, urine accumulator dump command, telemetry readout, a nitrogen supply for package atmospheric pressurization, a vacuum pump and plumbing system to simulate the metabolic waste container, and a means for both testing and monitoring numerous housekeeping functions within the experiment package. In addition, a portion of the console is designated for fluid handling during the calibration phase. This console is a two-bay, 6-ft high rack with a desk, which allows placement of the instrument and related hardware for testing. The second piece of AGE is a small battery-operated portable Gantry AGE unit. This unit simulates all of the electrical spacecraft functions and allows monitoring of many of the internal housekeeping functions in the package. This unit is intended to be used on the Launch Gantry during the final checkout of the experiment before flight and during those times when it is not feasible to have a large console attached to the unit. The Gantry AGE is powered from a self-contained rechargeable battery pack. These units are presented in Figs. F-1 through F-3, Appendix F.

[1]To establish calcium range only (a part of item 6 above).
[2]If word 13.

O. Urine Analysis Experiment

The following listing defines the information levels assigned to each of the 16 experiment data channels. They are divided into seven digital (science) words and nine analog (engineering) words. Typical level values for the digital as well as the analog words are given.

Data Format

Word	Definition
1	7 bits Ca^{++}
2	7 bits Ca^{++} temp
3	5 bits, GE accumulator dumps; 1 bit, urine or calibrate sequence; 1 bit, number of dilutions
4	7 bits creatinine
5	7 bits creatinine temp
6	7 bits creatine
7	7 bits creatine temp
8	Ca^{++} lamp current, I_p A
9	Cr–Cr lamp current, I_p B
10	lamp voltage Ca^{++}
11	lamp voltage Cr–Cr
12	4.5-Vdc battery voltage
13	bag-temp
14	experiment pressure
15	+4Vdc (sequencer power supply)
16	+15-Vdc voltage check (2.5Vdc normal)

1. Channel 1–7 (Science)

0 level voltage = 3.8 V

1 level voltage = 0.4 V

2. Channel 8, Lamp I_p, Cr–Cr I_p A

0 lamps *ON*

1 lamp *ON*, 2.50 ±0.15 V, 5 to 50°C

2 lamps *ON*, 1.25 ±0.15 V, 5 to 50°C

3. Channel 9, Lamp I_p, Ca·· I_p, B

0 lamps *ON*

1 lamp *ON*, 2.25 ± 0.15 V, 5 to 50°C

2 lamps *ON*, 1.00 ± 0.15 V, 5 to 50°C

*4. Channel 10, Lamp Voltage Ca··

V Ca·· = 2.75 V

5. Channel 11, Lamp Voltage Cr–Cr

V Cr–Cr = 2.5 V

6. Channel 12, Battery Voltage

V Bat = 4.5Vdc max

7. Channel 13, Bag Temp.

Temp.	5°C	35°C
E_0	1.5 V	4.2 V

8. Channel 14, Pressure Switch

7.5 psia $\leq P \leq$ 12.5 psia E_0 = 4.45 ±0.5V

$P <$ 7.5 psia E_0 = 1.96 ±0.5V

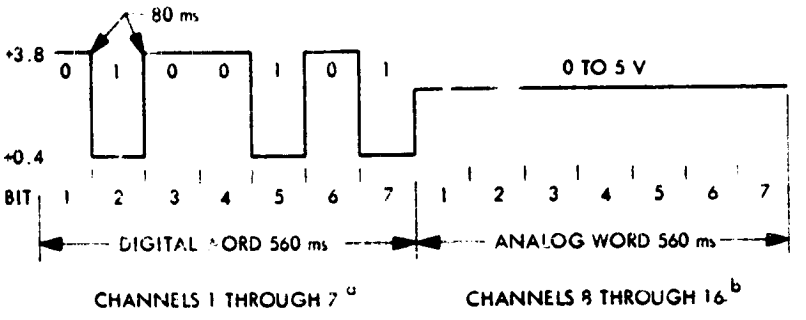
$P >$ 12.5 psia E_0 = 0.0 ±0.5V

9. Channel 15, Sequencer Power Supply (+4 V supply, 4.15 ± 0.70 V)

10. Channel 16, ± 15Vdc Supplies

IF ± 15Vdc supplies are normal, E_0 = 2.5Vdc

The telemetry channel then presents a series of data bits to the spacecraft for transmission to a ground station. A typical data series is given in Appendix E, Fig. E-1. Figure 7 shows the word format and typical levels to be expected.



[a] EACH CHANNEL CONSISTS OF SEVEN SEQUENTIAL BITS; EACH BIT IS PRESENTED TO THE TELEMETRY FOR A PERIOD OF 80 ms AT 12.5 bits/s. THE SEVEN-BIT BINARY-CODED WORD WILL RELATE TO THE VARIABLE UNDER MEASUREMENT.

[b] AS IN ITEM [a]. ALSO EACH OF THE SEVEN SEQUENTIAL BITS WILL BE OF THE SAME VOLTAGE AMPLITUDE. THE AMPLITUDE WILL RELATE TO THE VARIABLE UNDER MEASUREMENT.

NOTE: FALL AND RISE TIMES ≈ 100 μs

Fig. 7. Expected format and typical levels

Appendix A

Sequence of Analysis—Calcium and Creatine–Creatinine

The sequence of steps necessary to implement the analysis of calcium and creatine–creatinine is presented in Table A-1.

Table A-1. Calcium and Creatine-Creatinine fluorometry

Timing signals	Valve, V_1	Valve, V_2	Test Cell Pump Volume 20 turns	Waste pump Volume 0.23 ml	Comments
Calcium fluorometry					
t = 0, 3, 9, 15, 21, 24 (0) h	Urine	V_1–waste	Off	Off	Valve or pump positions at end of previous test
	Calib/urine	V_1–waste	Off	Off	t = 0, 24 h pulse sequences V_1 to the calibrate position
	Calib/urine	V_1–waste	Off	On	Flushes lines with calib or urine
	Calib/urine	V_1–waste	Off	Off	Cycle SW turn off
	Calib/urine	V_1–waste	On (−) 4 rev	Off	Fills test cell with calib or urine
	Calib/urine	V_1–waste	Off	Off	Count turns for switch turn-off
	Calib/urine	Reagent	Off	Off	
	Calib/urine	Reagent	On (−) 16 rev	Off	Fills test cell with reagent solution
	Calib/urine	Reagent	Off	Off	Limit SW turn-off
Mixing sequence	Blocked	Mix	Off	Off	
	Blocked	Mix	On (+) 20 rev	Off	Empty test cell
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (−) 20 rev	Off	Fill test cell. Mix 1
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (+) 20 rev	Off	Empty test cell
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (−) 20 rev	Off	Fill test cell. Mix 2
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (+) 20 rev	Off	Empty test cell
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (−) 20 rev	Off	Fill test cell. Mix 3
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (+) 20 rev	Off	Empty test cell
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (−) 20 rev	Off	Fill test cell. Mix 4
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (+) 20 rev	Off	Empty test cell
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (−) 20 rev	Off	Fill test cell. Mix 5
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (+) 20 rev	Off	Empty test cell
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (−) 20 rev	Off	Fill test cell. Mix 6
	Blocked	Mix	Off	Off	Limit SW turn-off

Table A-1 (contd)

Timing signals	Valve, V	Valve, V	Test Cell Pump Volume 20 turns	Waste pump Volume 0.23 ml	Comments
Calcium fluorometry (contd)					
Mixing sequence (contd)	Blocked	Mix	On (+) 20 rev	Off	Empty test cell
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (−) 20 rev	Off	Fill test cell. Mix 7
	Blocked	Mix	Off	Off	Limit SW turn-off
Ranging sequence	*Data Amplifier Output Greater than 4.7 V* If output of data amplifier is above 4.7 V, proceed with *Dilution Step "A"* followed by the mixing sequence. Then proceed to the DATA readout step. *Data Amplifier Output Less than 4.7 V* If output of data amplifier is less than 4.7 V, accomplish the following steps				
DATA readout	Read calcium fluorometer data and temperature into data system				
Final rinse sequence	Blocked	V_1–waste	Off	Off	
	Blocked	V_1–waste	On (+) 20 rev.	Off	Empty test cell
	Blocked	V_1–waste	Off	Off	
	Rinse	V_1–waste	Off	Off	
	Rinse	V_1–waste	Off	On	Waste pump on, flush V_1–V_2 line
	Rinse	V_1–waste	On (−) 20 rev	Off	Fill test cell with rinse fluid
	Rinse	V_1–waste	Off	Off	
	Block	Mix	Off	Off	
	Block	Mix	On (+) 20 rev	Off	Flush bathtub with rinse fluid from the test cell
	Block	Mix	On (−) 20 rev	Off	Returns rinse fluid to the test cell from the bathtub
	Block	Mix	Off	Off	
	Urine	V_1–waste	Off	Off	
Sequence completed	Urine	V_1–waste	On (+) 20 rev	Off	Empty test cell—end of sequence. Wait for next sequence initiation pulse at 3, 9, 15, 21 hours. V_1 sequence to urine position for these times
Dilution step A	Rinse	V_1–waste	Off	Off	
	Rinse	V_1–waste	Off	On	Rinses V_1 and V_2 of calib or urine prior to emptying test cell
	Rinse	V_1–waste	Off	Off	
	Block	V_1–waste	Off	Off	
	Block	V_1–waste	On (+) 20 rev	Off	Empty test cell
	Block	V_1–waste	On (−) 4 rev	Off	Fills test cell with 7th mixed sample
	Block	V_1–waste	Off	Off	
	Calib/urine	Reagent	Off	Off	
	Calib/urine	Reagent	On (−) 16 rev	Off	Fills test cell with reagent solution
	Calib/urine	Reagent	Off	Off	Limit switch turn-off

NOTES

V_1 connects urine or calibrate or rinse to V_2.

V_2 V_1–Waste connects test cell to valve V_1 and waste.
"reagent" connects test cell to reagent.
"blocked" blocks test cell.

Rev refers to revolutions of test cell micro syringe piston gear drive

Table A-1 (contd)

Timing signals	Valve, V_1	Valve, V_2	Test Cell Pump Volume 20 turns	Waste pump Volume 0.23 ml	Comments
Creatine-creatinine colorimetry					
t = 0, 3, 9, 15, 21, 24 (0) h	Urine	V_1 waste	Off	Off	Valve or pump positions at end of previous test
	Calib/urine	V_1 waste	Off	Off	t = 0, 24 h pulse sequences V_1 to the calibrate position
	Calib/urine	V_2–waste	Off	On	Flushes lines with calib or urine
	Calib/urine	V_2–waste	Off	Off	Cycle SW turn-off
Acid dilution sequence	Calib/urine	V_2–waste	On (−) 4 rev	Off	Fills test cell with calib or urine
	Calib/urine	V_2–waste	Off	Off	Count turns for turn-off
	Calib/urine	H_2SO_4	Off	Off	
	Calib/urine	H_2SO_4	On (−) 16 rev	Off	Acid added to calib or urine sample
	Calib/urine	H_2SO_4	Off	Off	Limit SW turn-off
Mixing sequence A	Blocked	Mix	Off	Off	
	Blocked	Mix	On (+) 20 rev	Off	Empty test cell
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (−) 20 rev	Off	Fill test cell. Mix 1
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (+) 20 rev	Off	Empty test cell
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (−) 20 rev	Off	Fill test cell. Mix 2
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (+) 20 rev	Off	Empty test cell
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (−) 20 rev	Off	Fill test cell. Mix 3
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (+) 20 rev	Off	Empty test cell
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (−) 20 rev	Off	Fill test cell. Mix 4
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (+) 20 rev	Off	Empty test cell
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (−) 20 rev	Off	Fill test cell. Mix 5
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (+) 20 rev	Off	Empty test cell
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (−) 20 rev	Off	Fill test cell. Mix 6
	Blocked	Mix	Off	Off	Limit SW turn-off

Table A-1 (contd)

Timing signals	Valve, V_1	Valve, V_2	Test Cell Pump Volume 20 turns	Waste pump Volume 0.23 ml	Comments
Creatine-creatinine colorimetry (contd)					
Mixing sequence A (contd)	Blocked	Mix	On (+) 20 rev	Off	Empty test cell
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (−) 20 rev	Off	Fill test cell. Mix 7
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Blocked	Off	Off	
	After V_2 sequences to the blocked position, turn on the heater at the next 5-min timing pulse. Heat for 25 min (five more 5-min pulses), turn off heater at the end of 25 min. Cool for 5 min (one more 5-min pulse). Proceed with next step: 2nd Dilution Sequence (Alkaline Picrate). **Delete the above sequence for the creatinine analysis, proceed directly to the following Rinse Sequence from the end of the mixing sequence A.				
Rinse sequence	Rinse	V_1–waste	Off	Off	
	Rinse	V_1–waste	Off	On	Picric acid rinse of V_1 and V_2 of calibration/urine fluids prior to emptying test cell
	Rinse	V_1–waste	Off	Off	
	Rinse	V_1–waste	Off	Off	
2nd Dilution (alkaline-picrate)	Blocked	V_1–waste	Off	Off	
	Blocked	V_1–waste	On (+) 20 rev	Off	Empty test cell
	Blocked	V_1–waste	On (−) 4 rev	Off	Fills test cell to 4/20 with acid/urine mix
	Rinse	V_1–waste	Off	Off	
	Rinse	V_1–waste	Off	On	Flushes lines with picric acid
	Rinse	V_1–waste	Off	Off	
	Rinse	V_1–waste	On (−) 8 rev	Off	Fills test cell to 12/20 with picric acid
	Rinse	V_1–waste	Off	Off	
	Blocked	Reagent	Off	Off	
	Blocked	Reagent	On (−) 8 rev	Off	Fills test cell to 20/20 with NaOH
	Blocked	Reagent	Off	Off	
	Blocked	Mix	Off	Off	
Mixing sequence B	Blocked	Mix	On (+) 20 rev	Off	Empty test cell
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (−) 20 rev	Off	Fill test cell. Mix 1
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (+) 20 rev	Off	Empty test cell
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (−) 20 rev	Off	Fill test cell. Mix 2
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (+) 20 rev	Off	Empty test cell
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (−) 20 rev	Off	Fill test cell. Mix 3
	Blocked	Mix	Off	Off	Limit SW turn-off

Table A-1 (contd)

Timing signals	Valve, V_1	Valve, V_2	Test Cell Pump Volume 20 turns	Waste pump Volume 0.23 ml	Comments
Creatine-creatinine colorimetry (contd)					
Mixing sequence B (contd)	Blocked	Mix	On (+) 20 rev	Off	Empty test cell
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (−) 20 rev	Off	Fill test cell. Mix 4
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (+) 20 rev	Off	Empty test cell
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (−) 20 rev	Off	Fill test cell. Mix 5
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (+) 20 rev	Off	Empty test cell
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (−) 20 rev	Off	Fill test cell. Mix 6
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (+) 20 rev	Off	Empty test cell
	Blocked	Mix	Off	Off	Limit SW turn-off
	Blocked	Mix	On (−) 20 rev	Off	Fill test cell. Mix 7
	Blocked	Mix	Off	Off	Limit SW turn-off
	Count next six 5-min pulses, then read optical density of test/reference cells and transfer data to data handling system at the sixth pulse (25–30 min after mixing).				
Final rinse sequence	Blocked	V_1–waste	Off	Off	
	Blocked	V_1–waste	On (+) 20 rev	Off	Empty test cell
	Blocked	V_1–waste	Off	Off	
	Rinse	V_1–waste	Off	Off	
	Rinse	V_1–waste	Off	On	Flush lines with picric acid rinse
	Rinse	V_1–waste	Off	Off	Cycle SW turn-off
	Rinse	V_1–waste	On (−) 20 rev	Off	Fill test cell with rinse
	Rinse	V_1–waste	Off	Off	Limit SW turn-off
	Blocked	Mix	Off	Off	
	Blocked	Mix	On (+) 20 rev	Off	Empty rinse from test cell into mixing chamber
	Blocked	Mix	On (−) 20 rev	Off	Empty mixing chamber into test cell thereby rinsing mixing chamber
	Blocked	Mix	Off	Off	
	Urine	V_1–waste	Off	Off	
	Urine	V_1–waste	On (+) 20 rev	Off	Empty test cell of rinse fluid. Limit SW turn-off
Sequence completed	Urine	V_1–waste	Off	Off	End of sequence--wait for next sequence initiation pulse at 3, 9, 15, 21 h. V_1 sequences to urine position for these times

NOTES

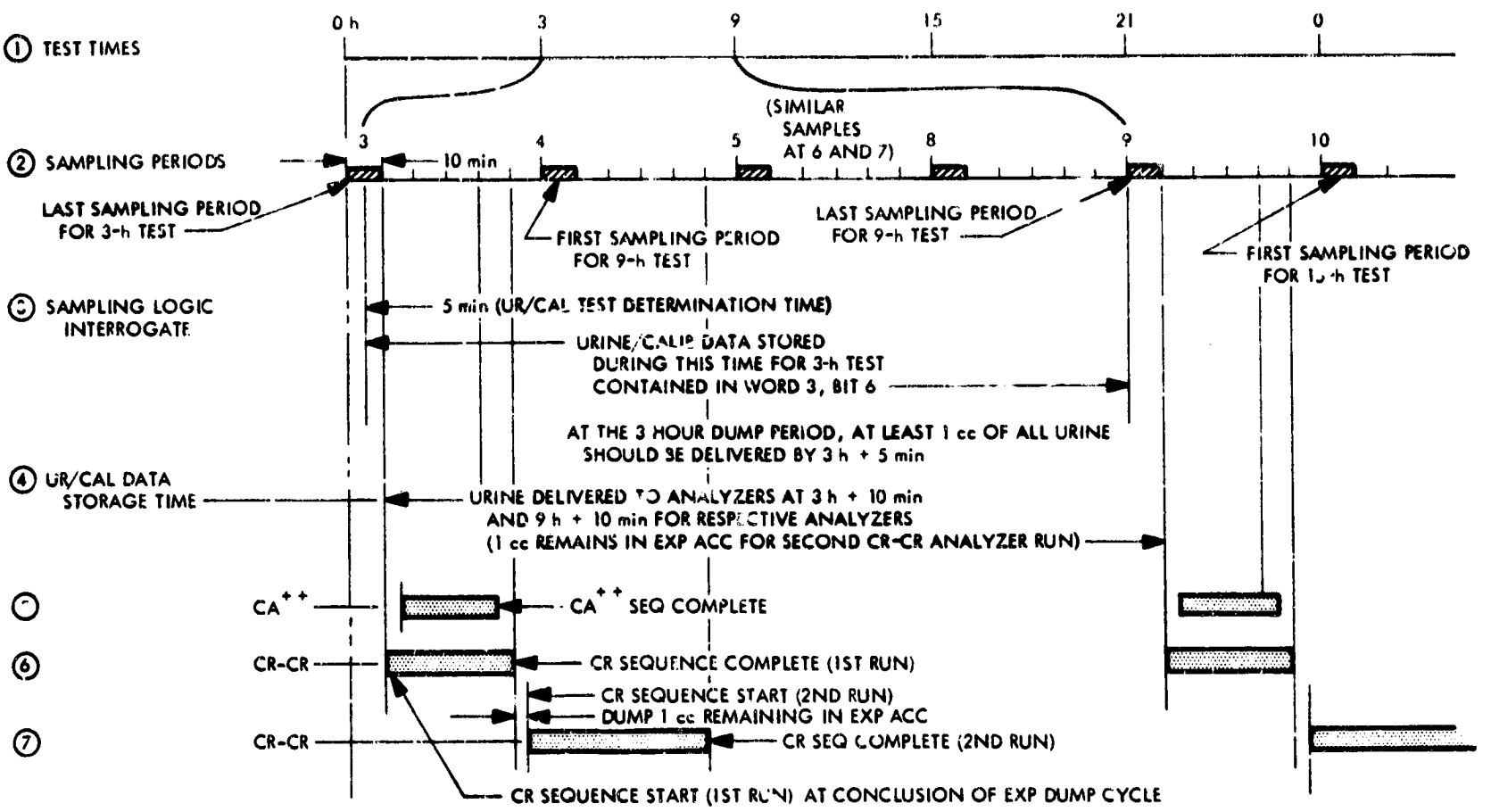
V_1 connects urine or calibrate or picric acid rinse to V_2.

V_2 "V_1–waste" connects test cell to valve V_1 and waste.
"reagent" connects test cell to reagent (Sodium Hydroxide; NaOH).
"blocked" blocks test cell.

rev refers to revolutions of test cell micro syringe gear drive.

Appendix B
Experiment Mechanical Configuration, Including Fluid Handling, Fluid Storage, Interface Requirements, and Analyzer Configurations

The instruments and major components necessary to conduct the chemical analyses are presented in Figs. B-1 through B-12.



NOTE: AT 0 h, SAMPLING MAY OCCUR. EXP ACC IS NOT EMPTIED AT 0 h + 10 min.
AT 0 h, CALIBRATION SOLUTION IS DRAWN FROM CALIBRATION FLUID BAG
TO PERFORM CALIBRATION SEQUENCE FOR CA^{++} AND CR CR

Fig. B-1. Fluid sampler sequence

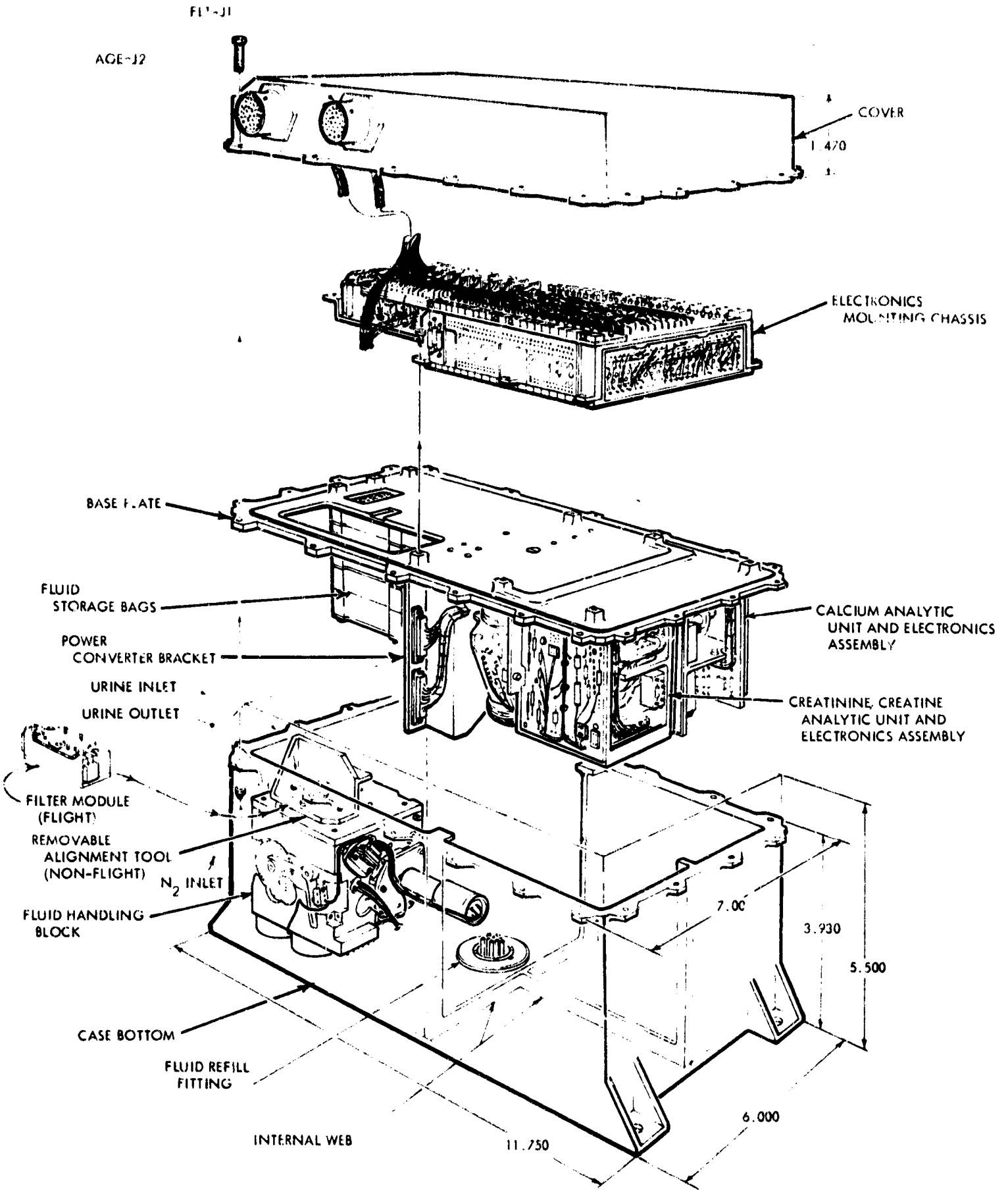
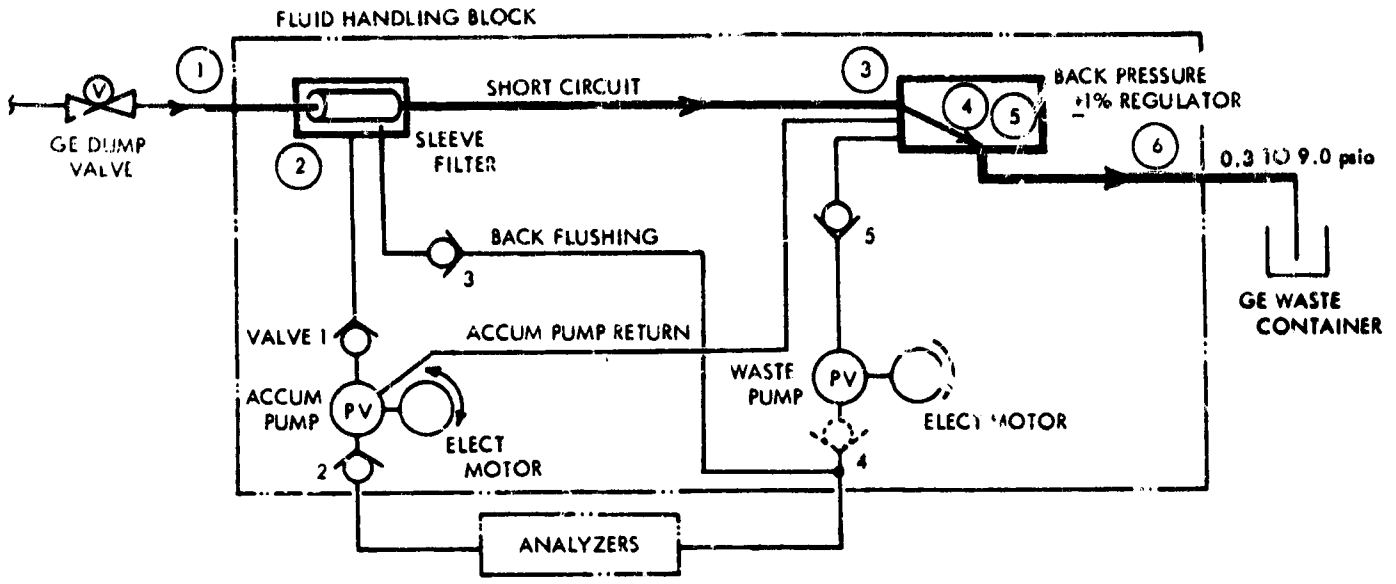


Fig. B-2. Initial breakdown of components



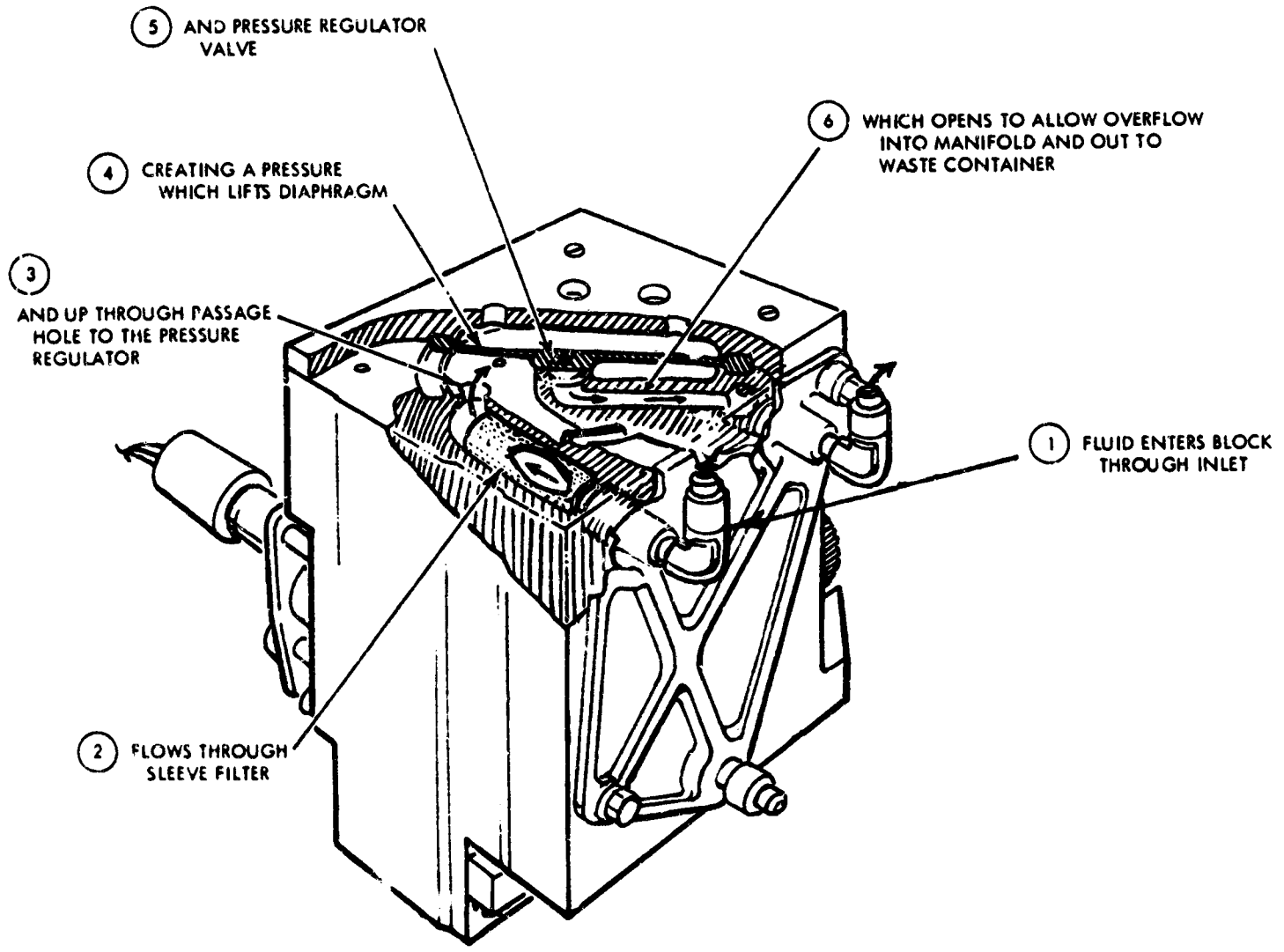


Fig. B-3. Fluid-handling block—short-circuit flow

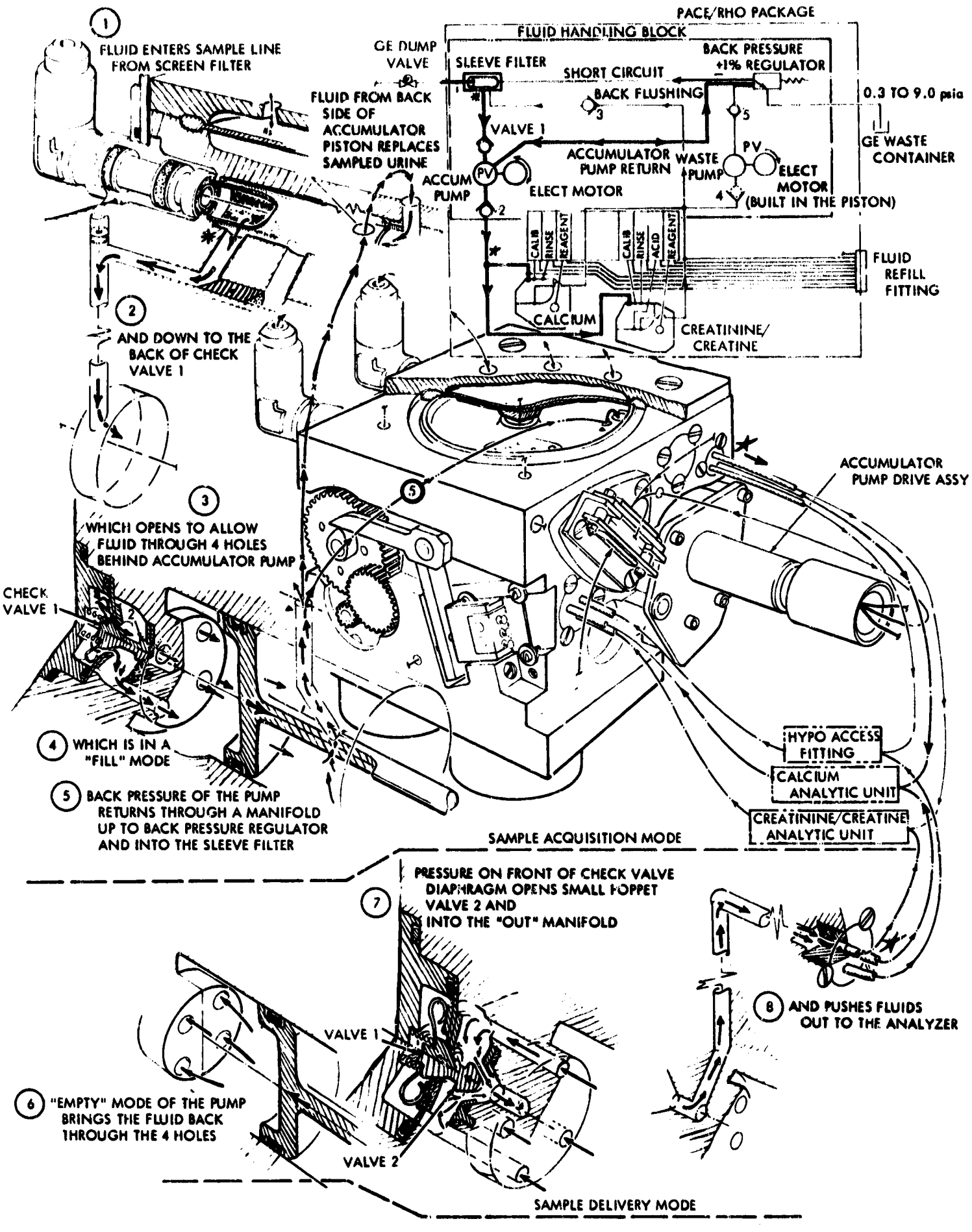


Fig. B-4. Fluid-handling block—passage of fluids from source to analyzer

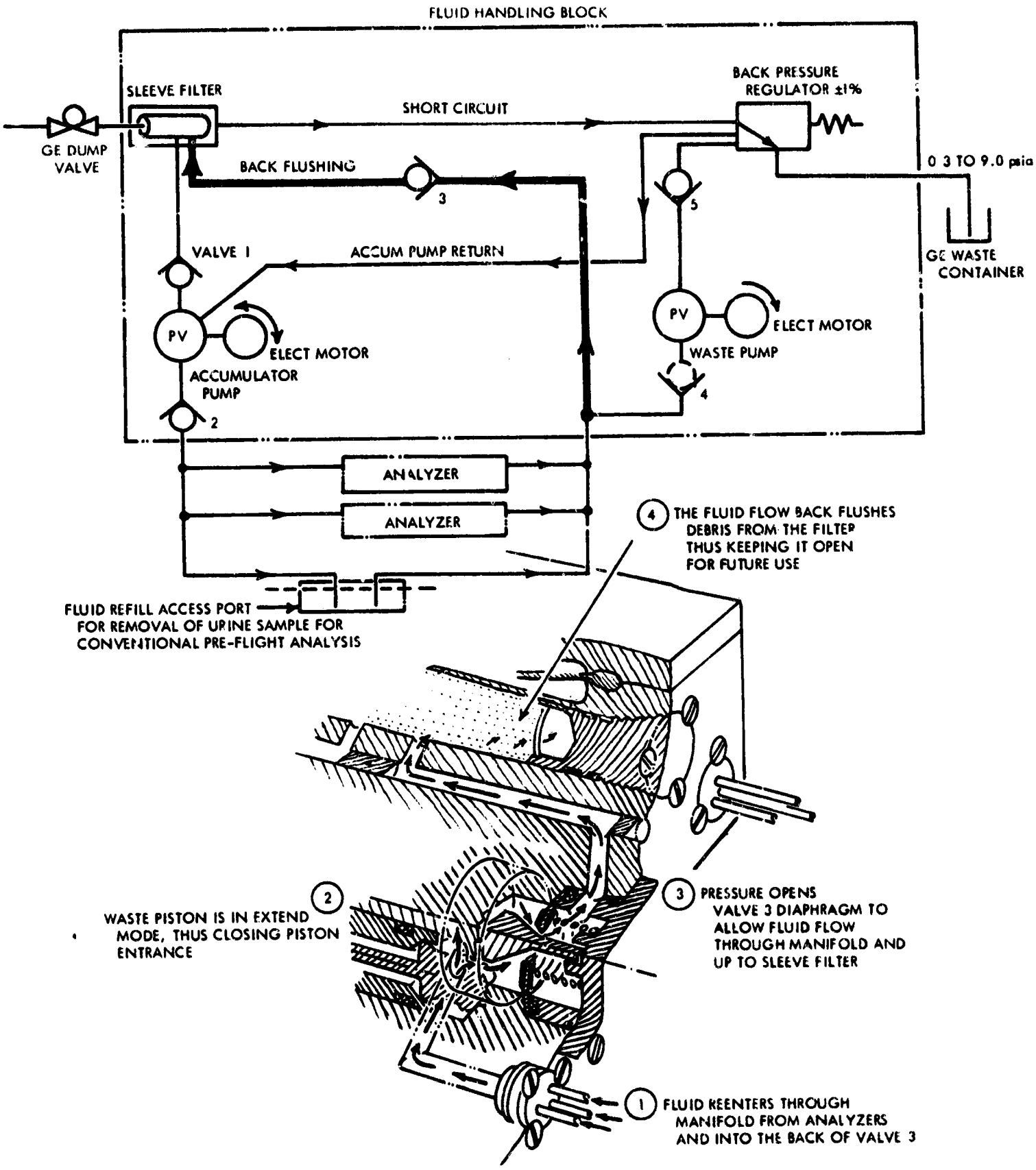


Fig. B-5. Fluid-handling block—backflushing

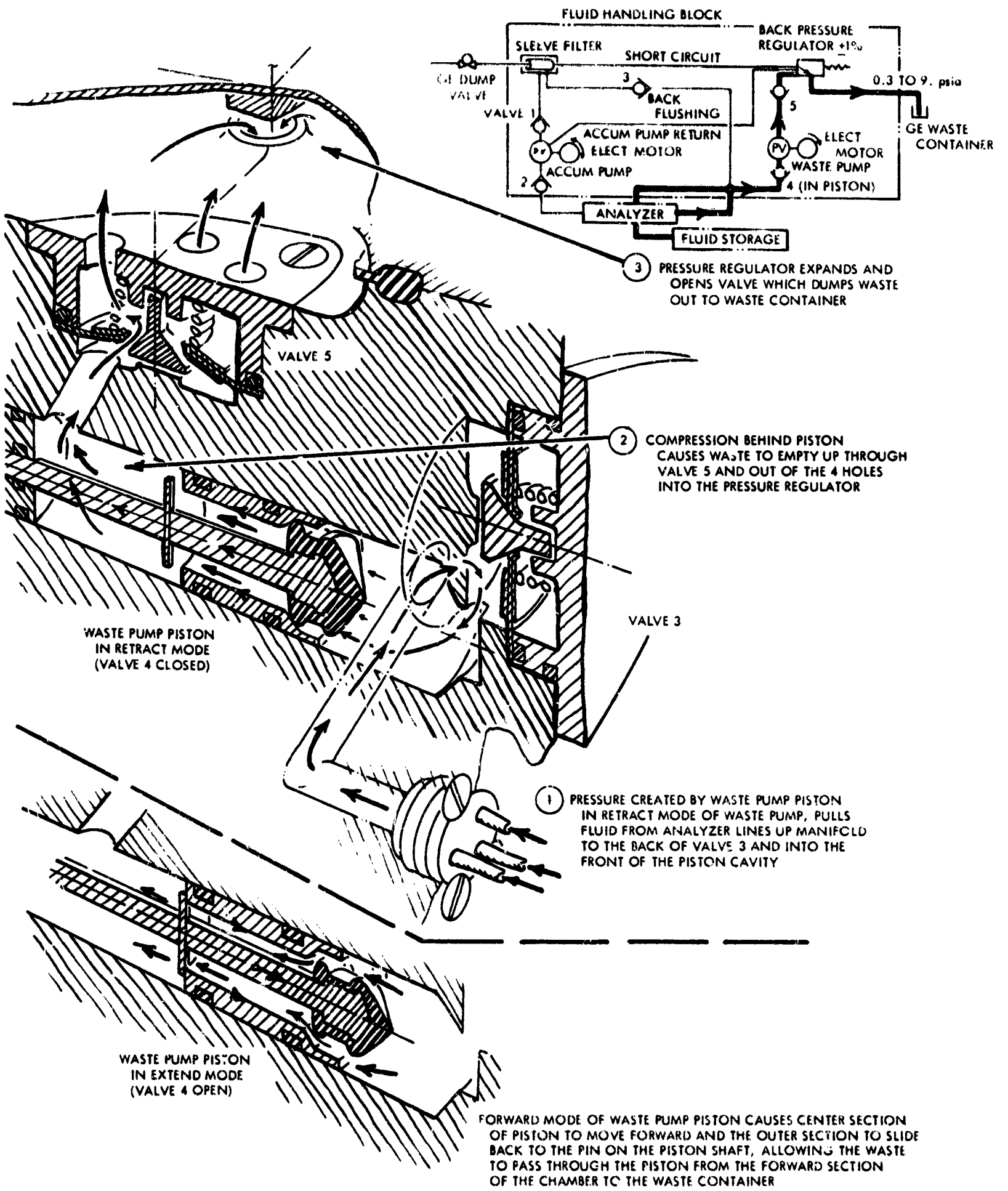


Fig. B-6. Waste pump operation cycle

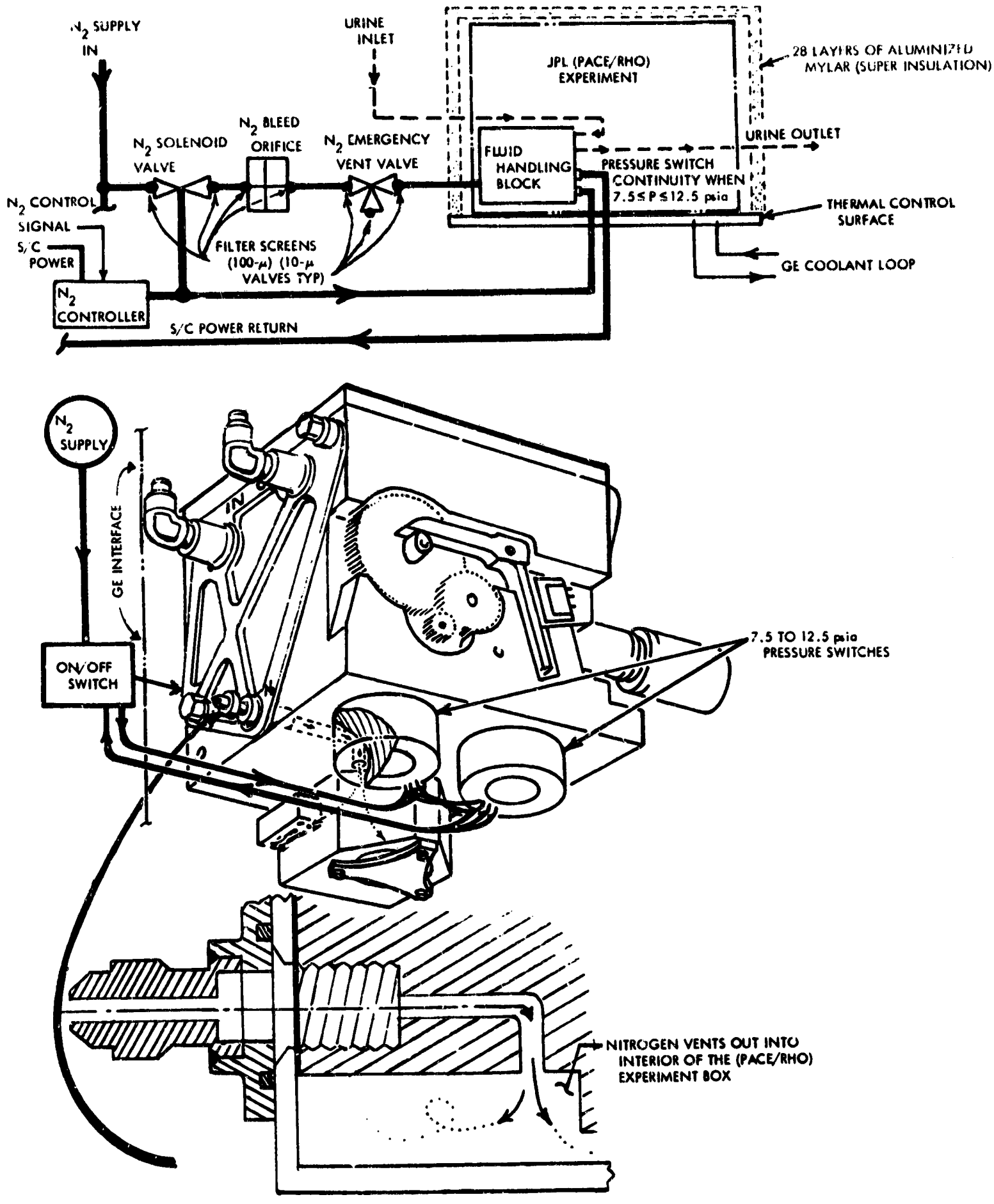


Fig. B-7. Fluid-handling block—Nitrogen pressurization

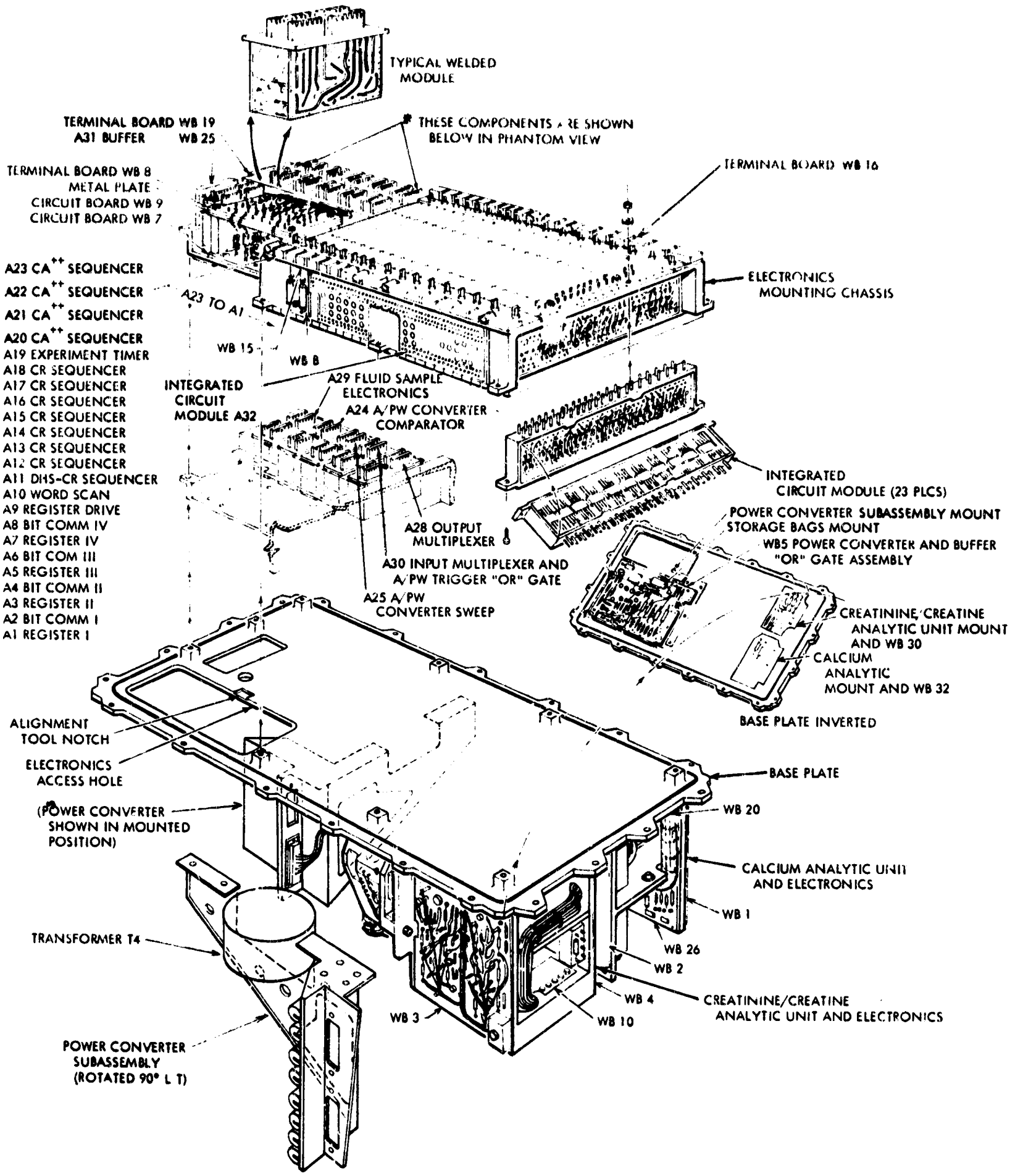


Fig. B-8. Electronics mounting chassis and base plate

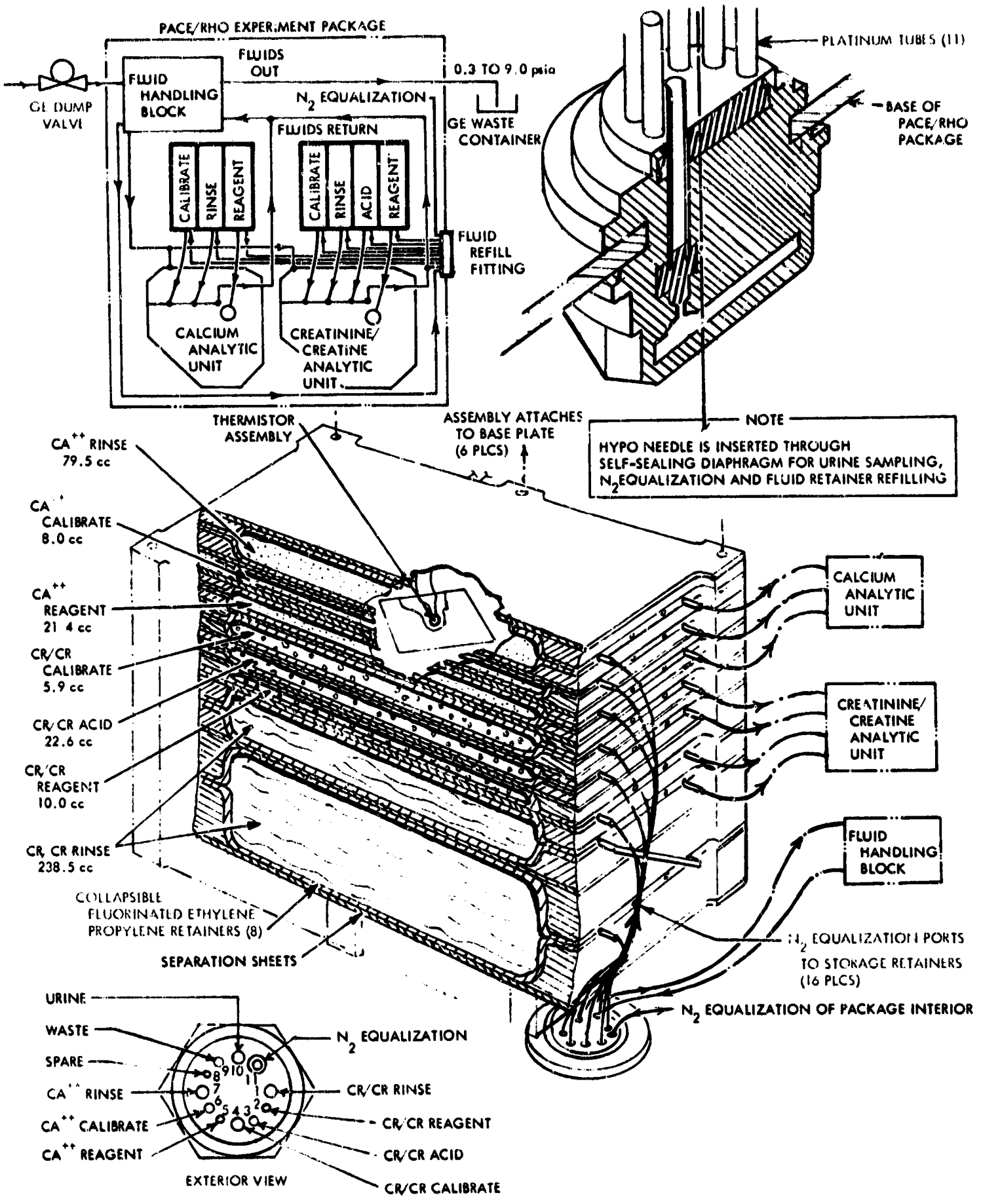


Fig. B-9. Fluid storage bags assembly and fluid refill fitting

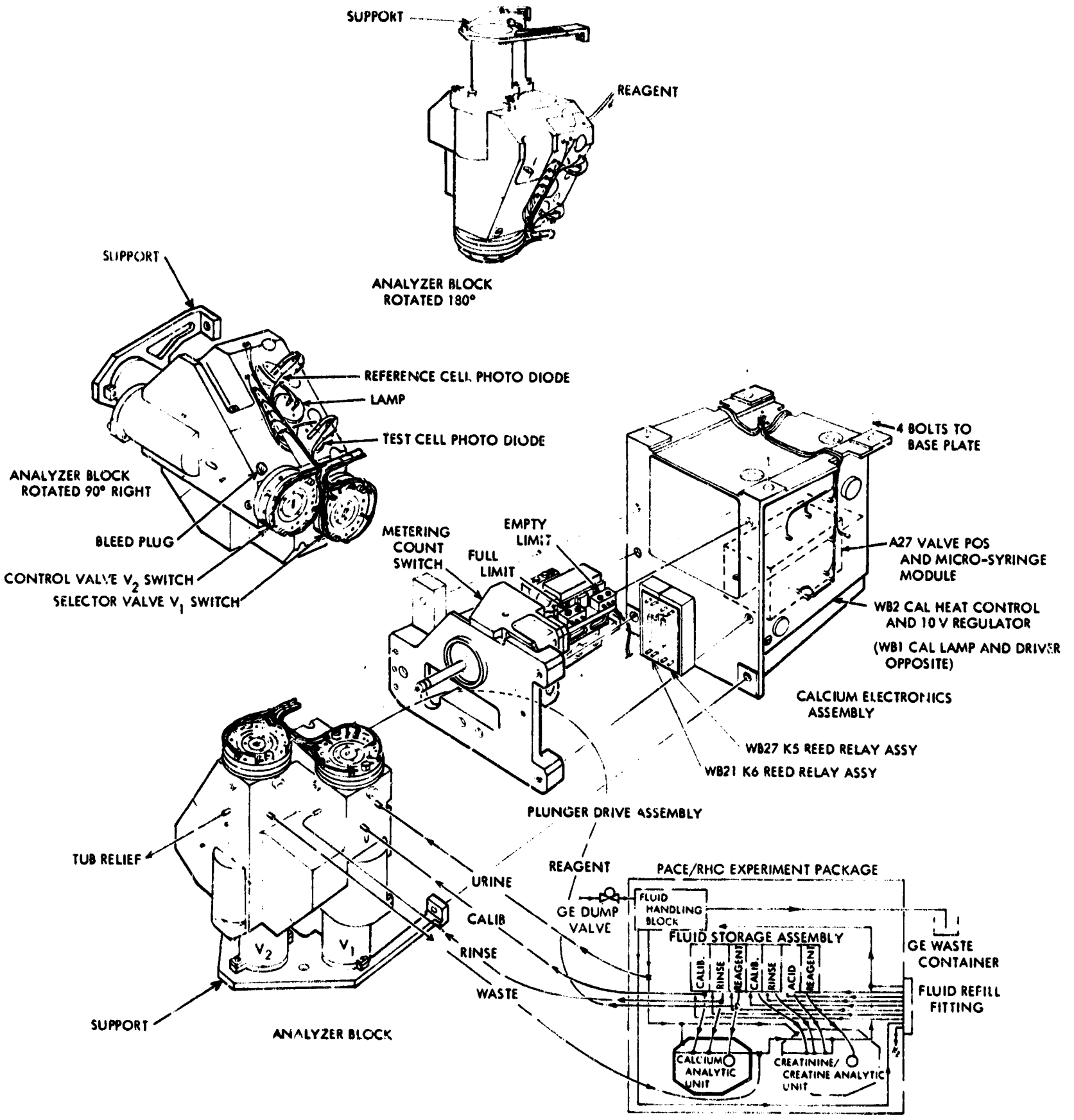


Fig. B-10. Calcium analyzer unit and electronics

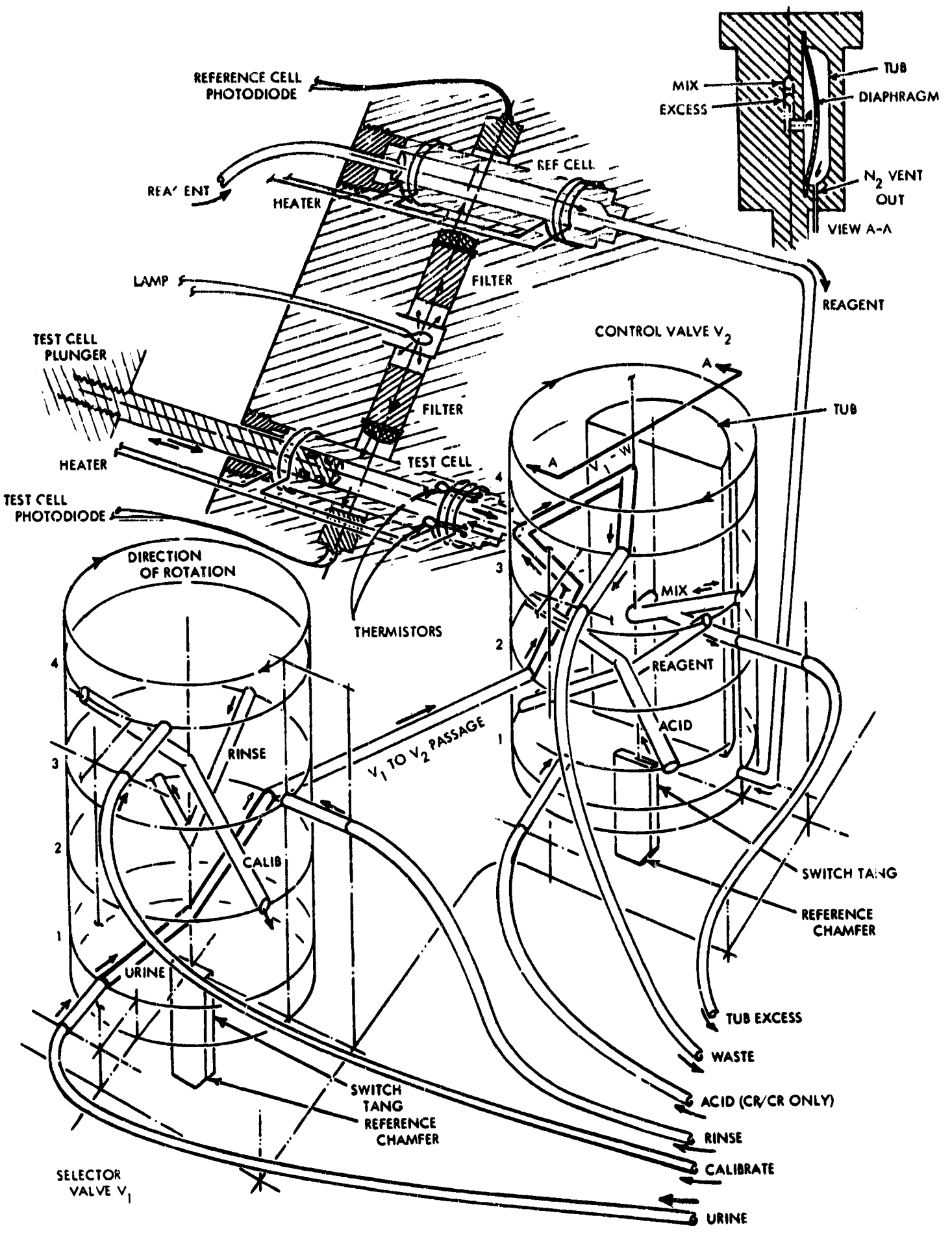


Fig. B-11. Analyzer test cells, valving, and optics

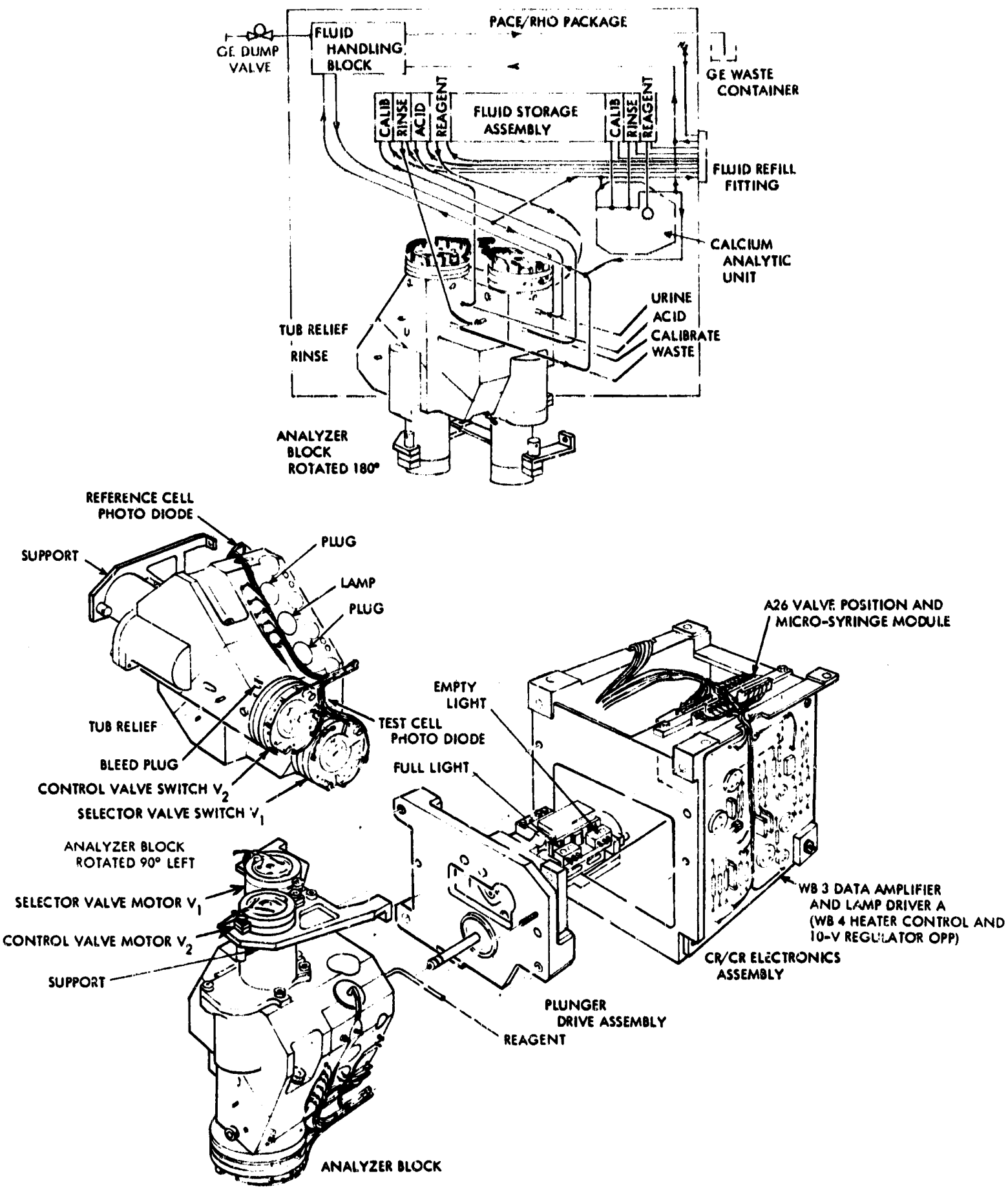


Fig. B-12. Creatinine-creatine analyzer unit and electronics assembly

Appendix C
Experiment Package

Figures C-1 through C-4 present various views of the experiment package.

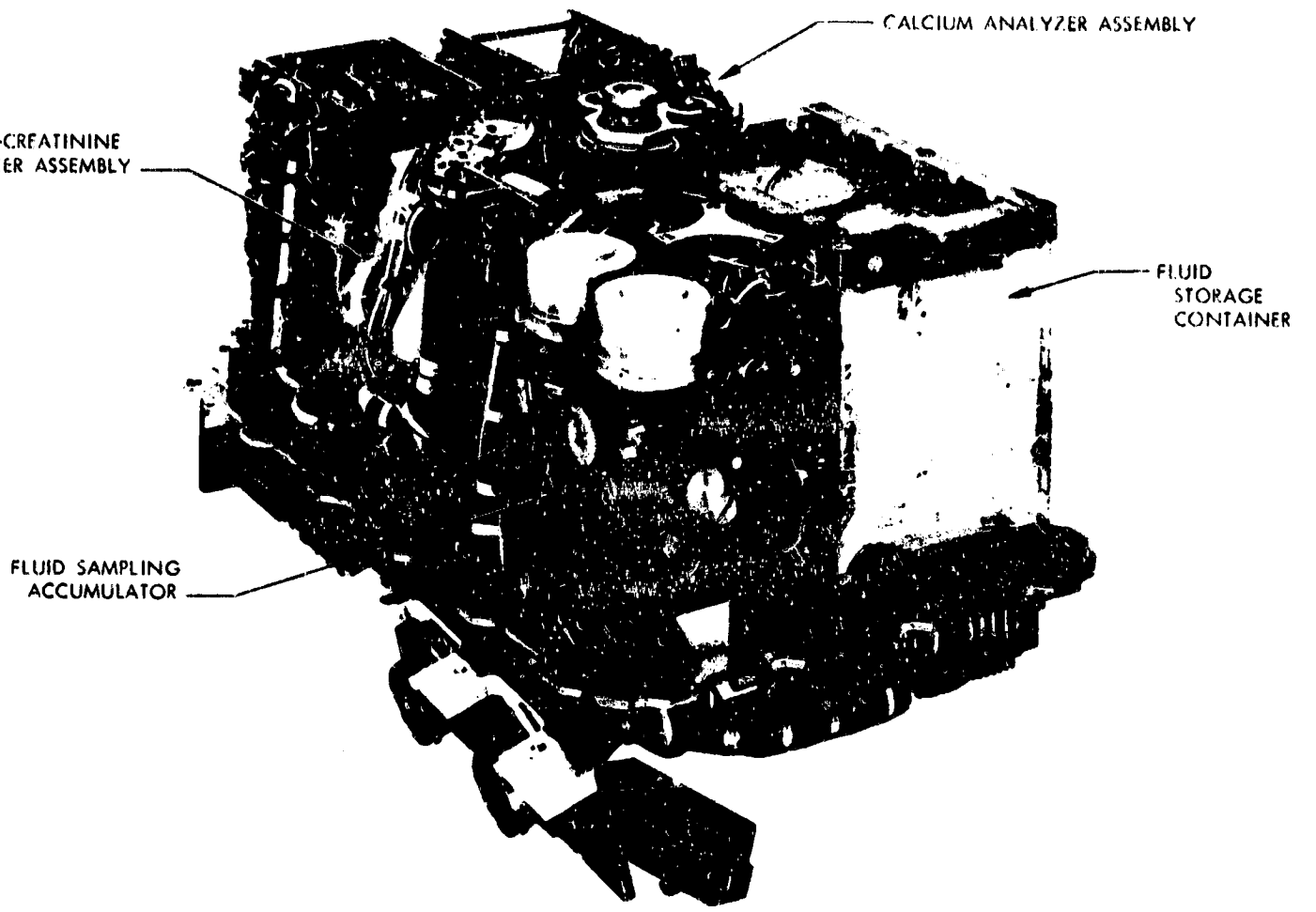


Fig. C-1. Fluid-sampling accumulator and fluid storage containers—oblique view

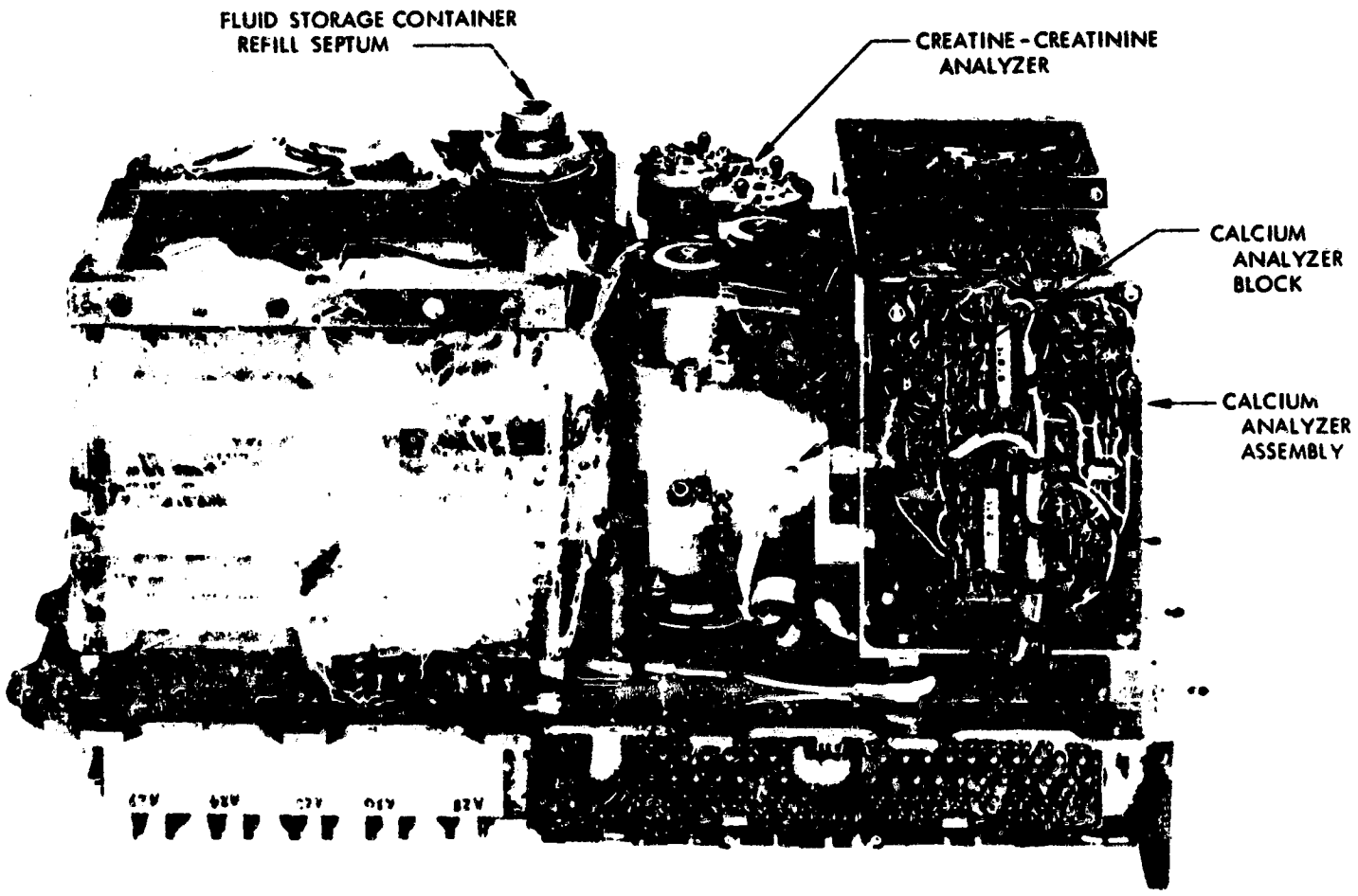


Fig. C-2. Fluid storage unit, calcium analyzer, calcium analyzer data amplifier, and sequencing electronics—side view

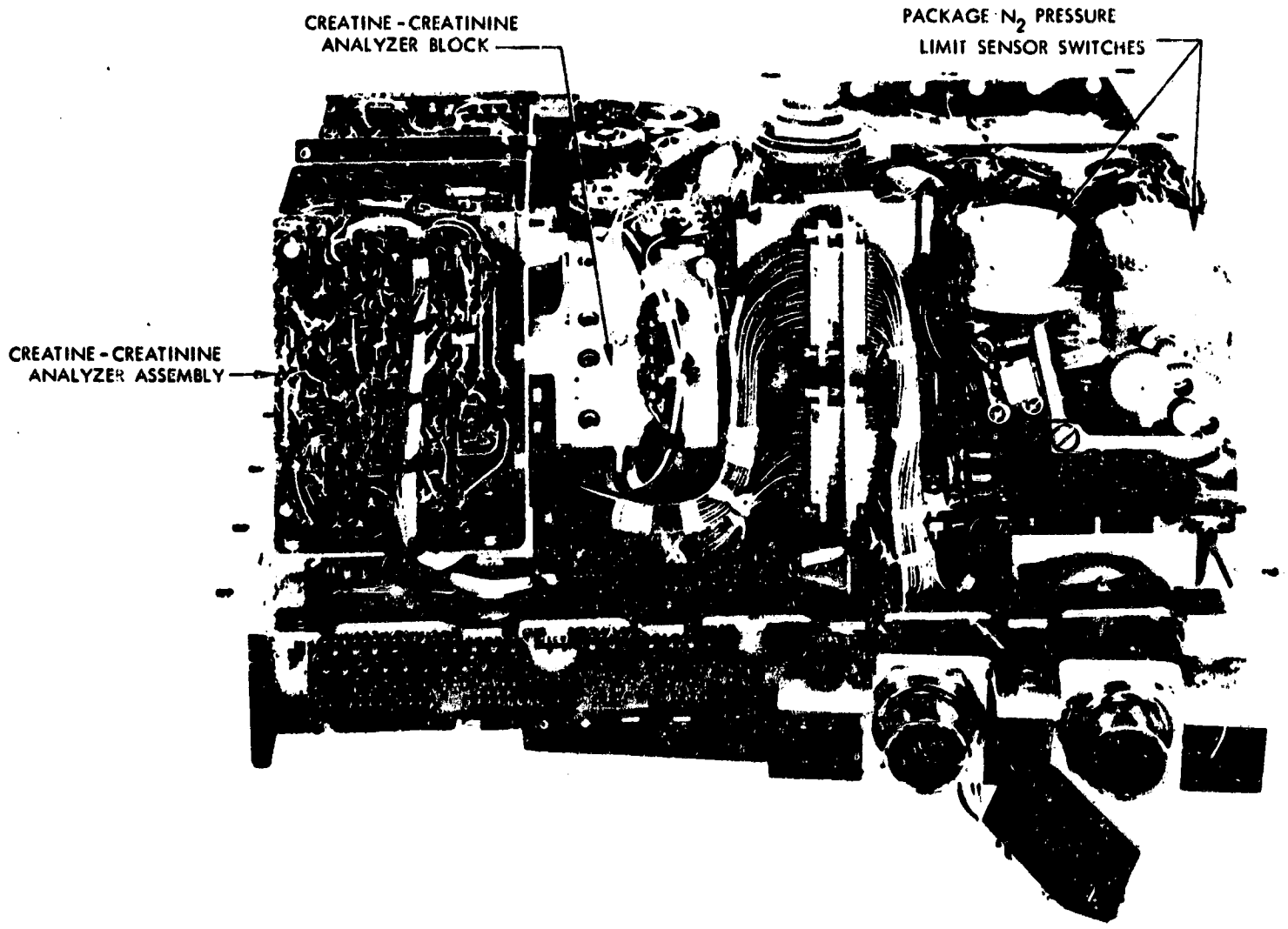


Fig. C-3. Creatine-creatinine data amplifier, creatine-creatinine analyzer, fluid sampling accumulator, and sequencing electronics—side view

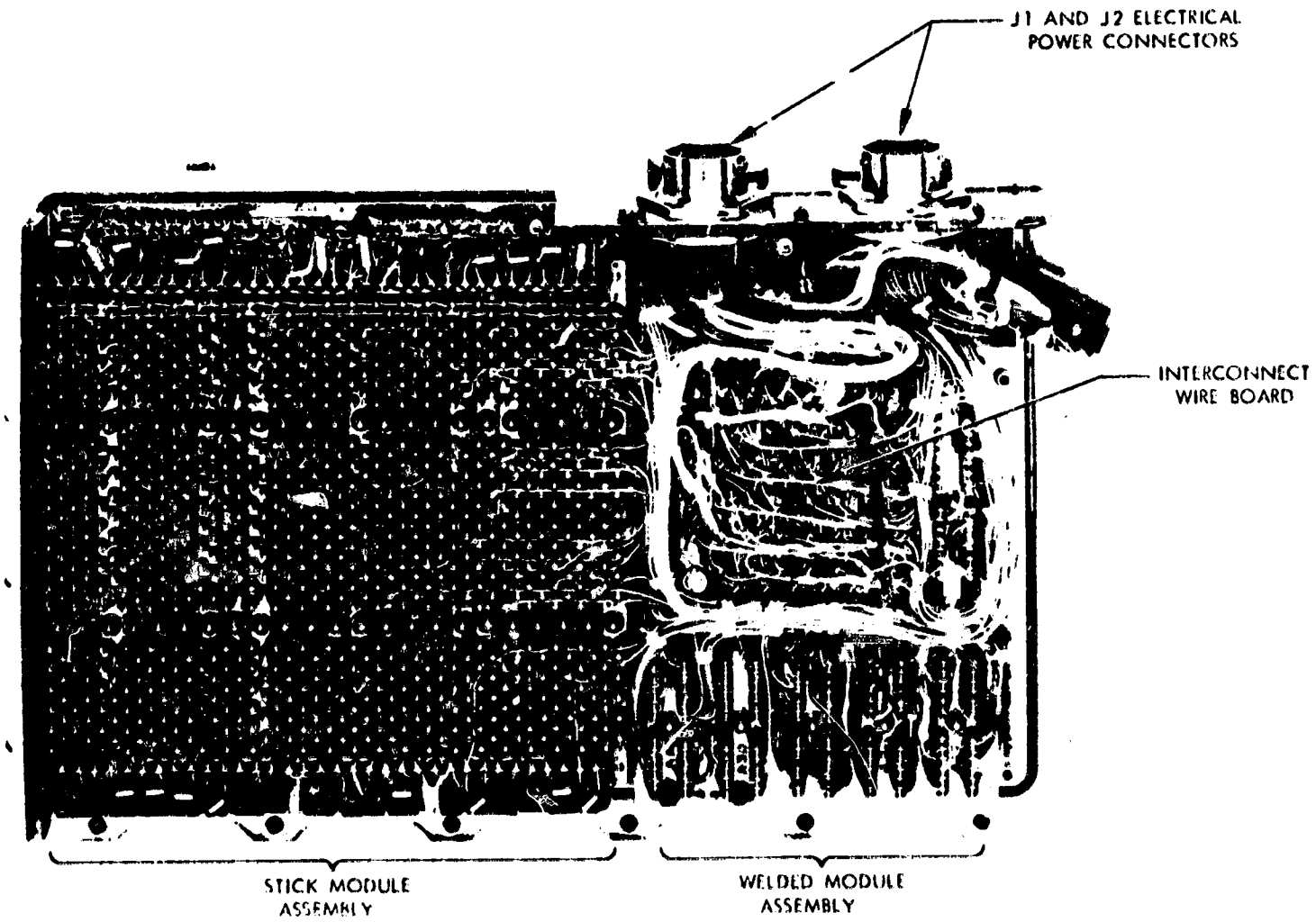


Fig. C-4. Electronic sequencer interconnections

Appendix D

Experiment Block Diagrams

The block diagrams in this appendix (Figs. D-1 through D-11) relate the logic sequencing requirements of Table A-1 to the functional electronics and fluid logic necessary to implement these analytical sequences. Figure 6 is a simplified functional block diagram of the figures in this appendix.

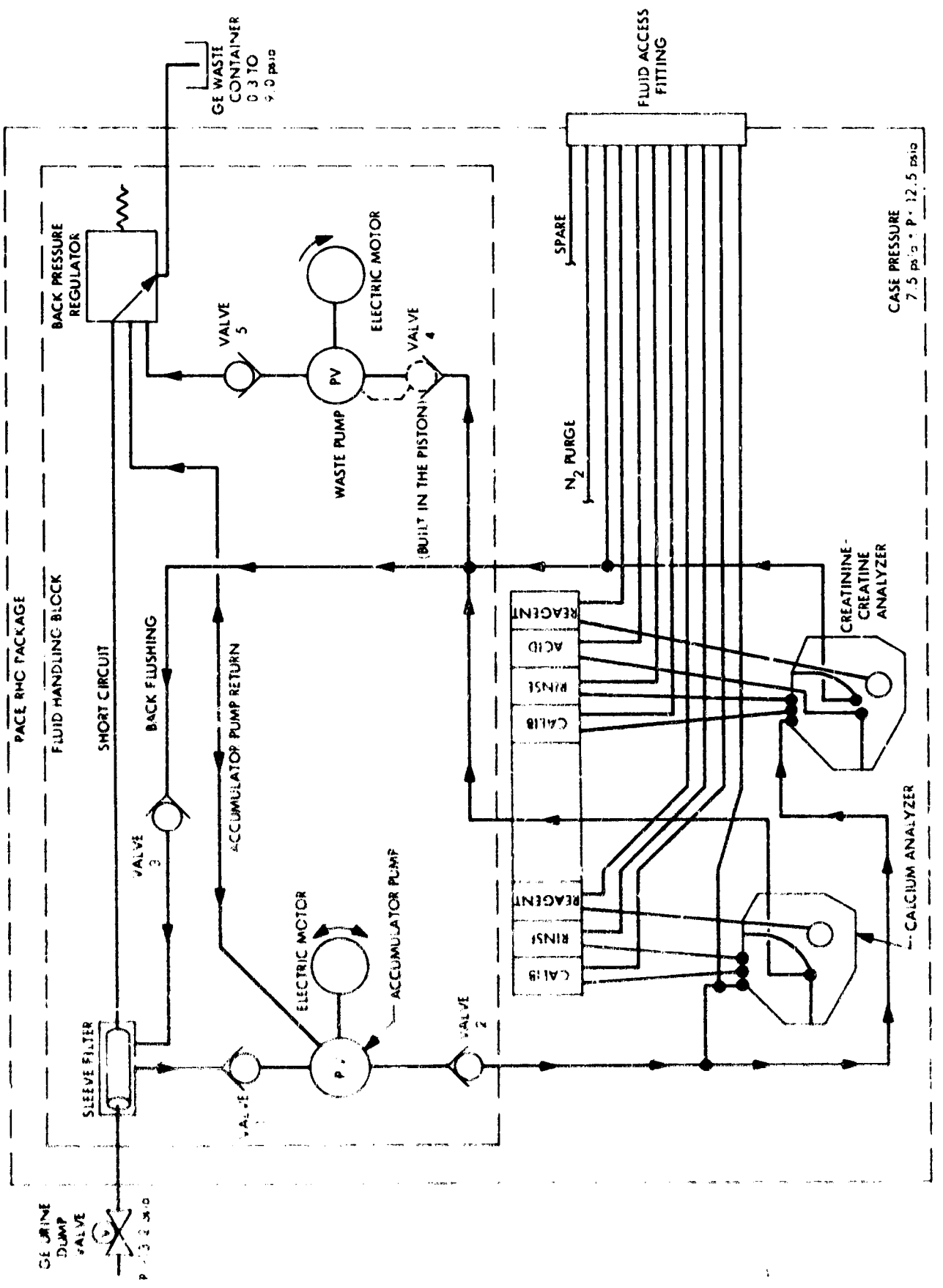


Fig. D-1. Fluid schematic

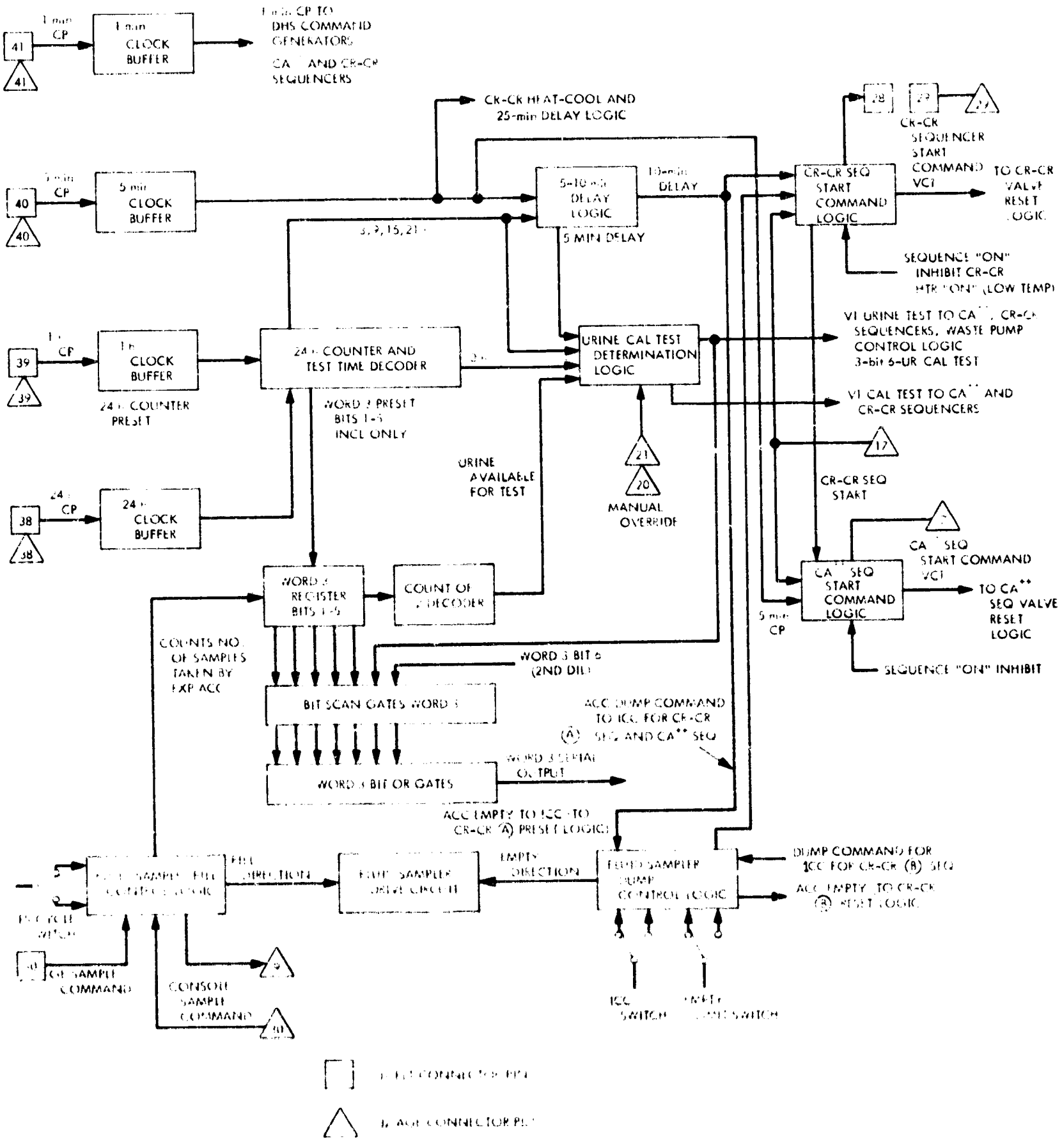


Fig. D-2. Experiment timer

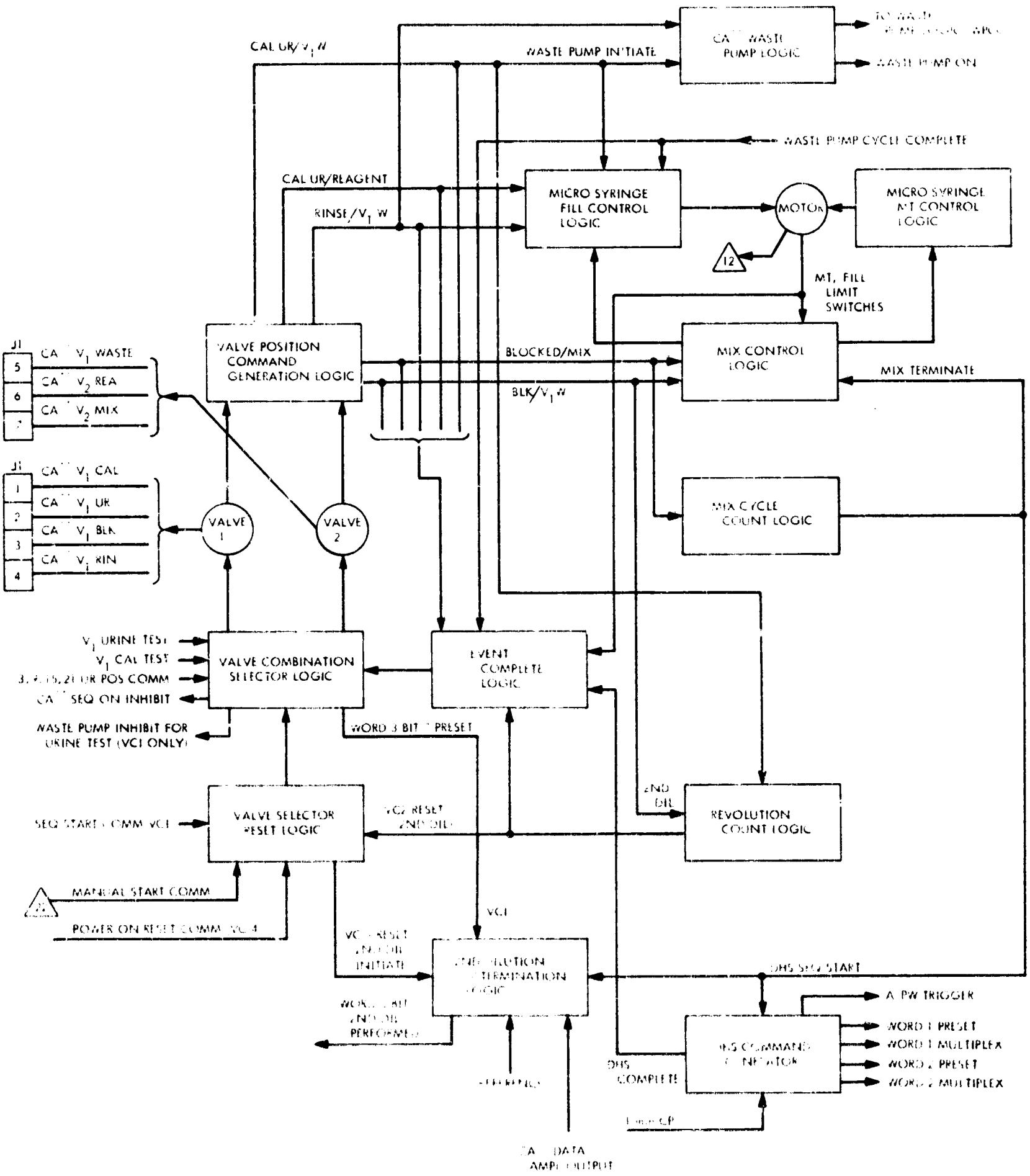


Fig. D-3. Calcium sequencer

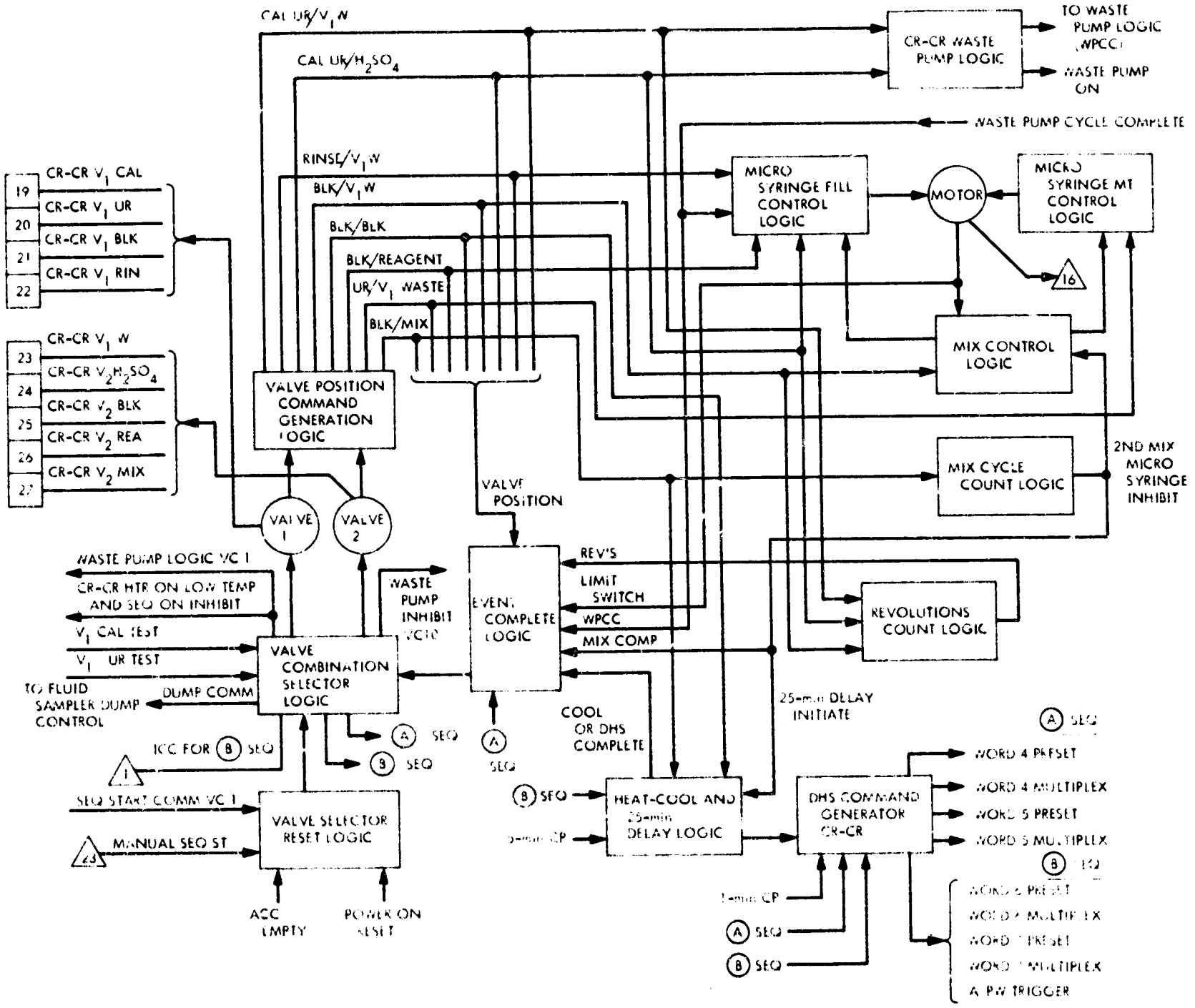


Fig. D-4. Creatine sequencer

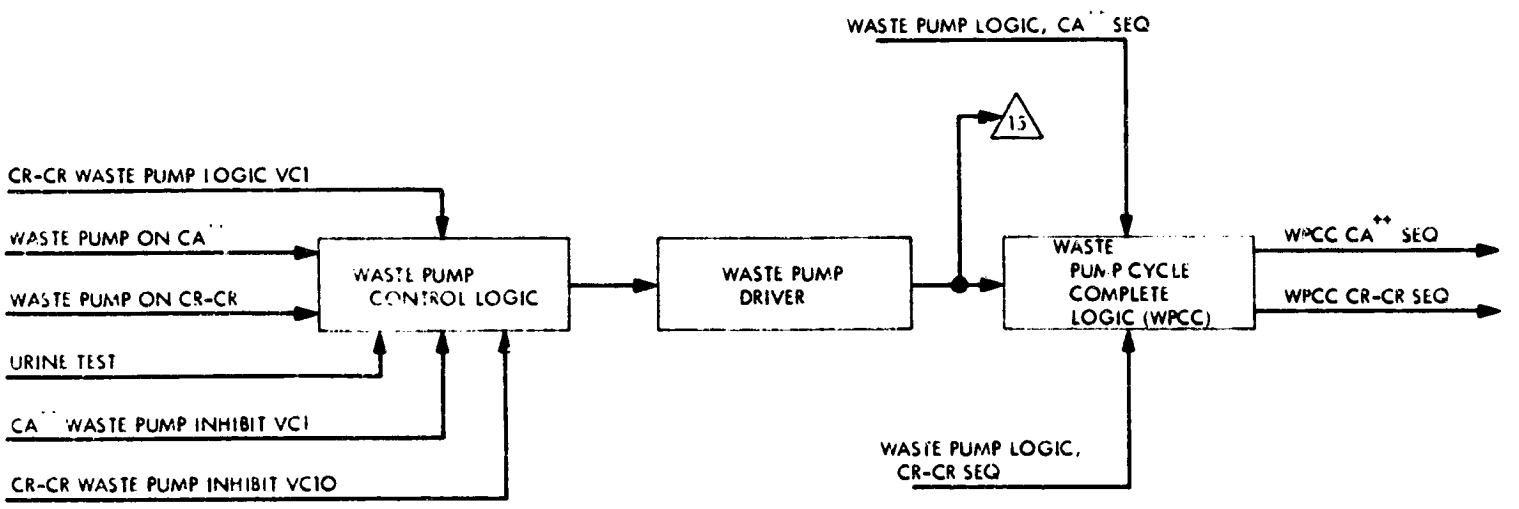


Fig. D-5. Waste pump logic

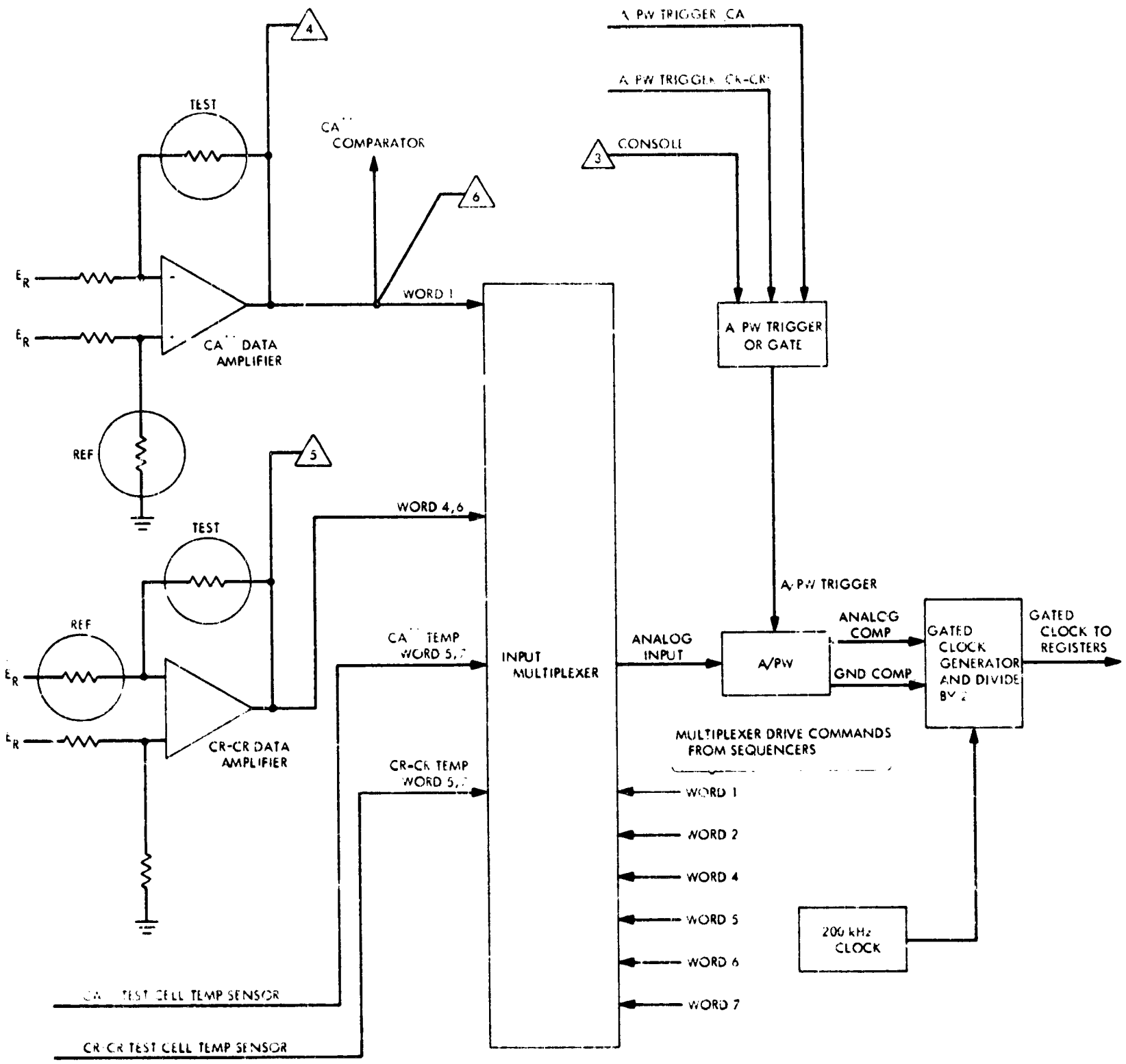


Fig. D-6. Data-handling system, data encoder

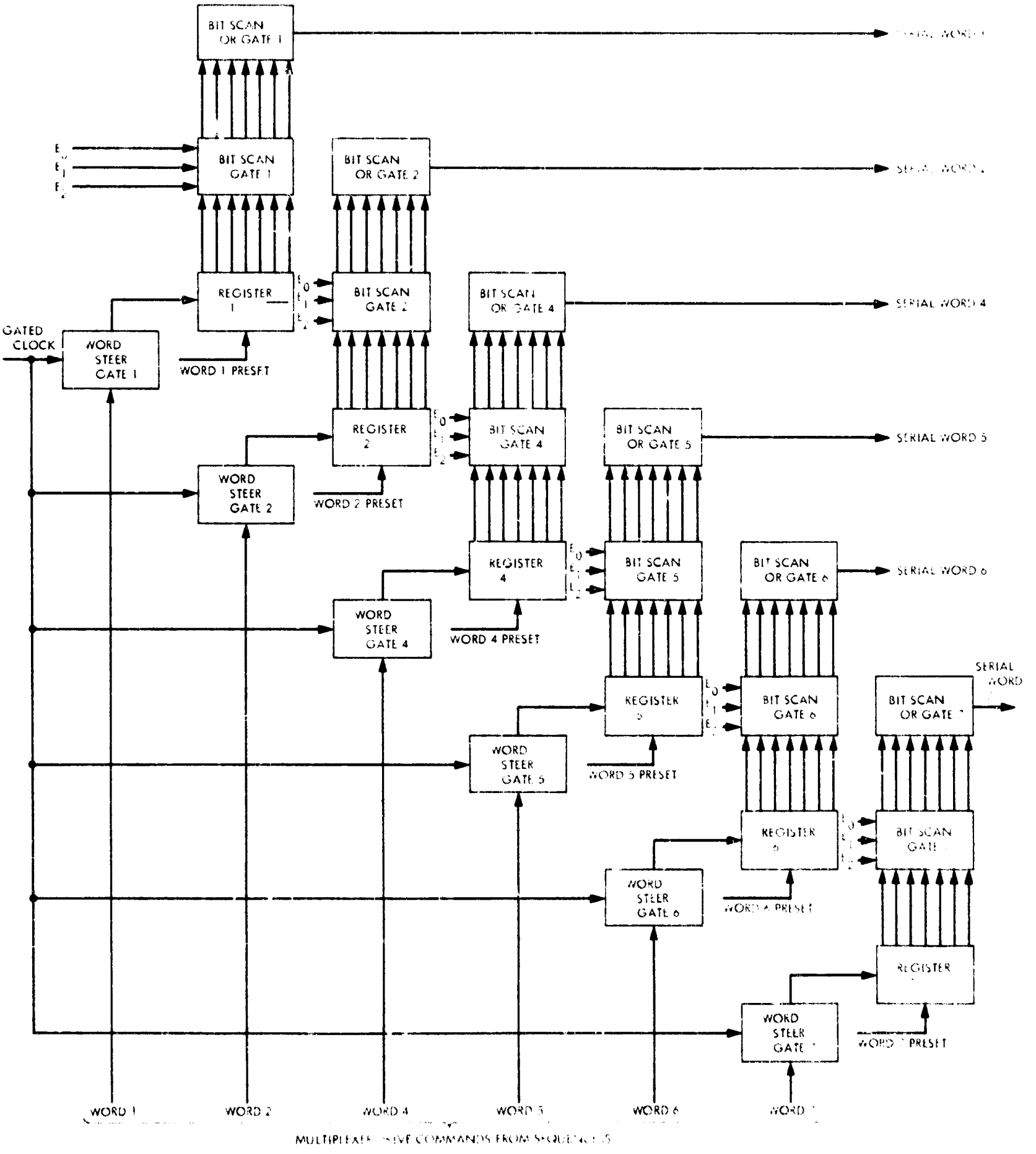


Fig. D-7. Data-handling system, data storage

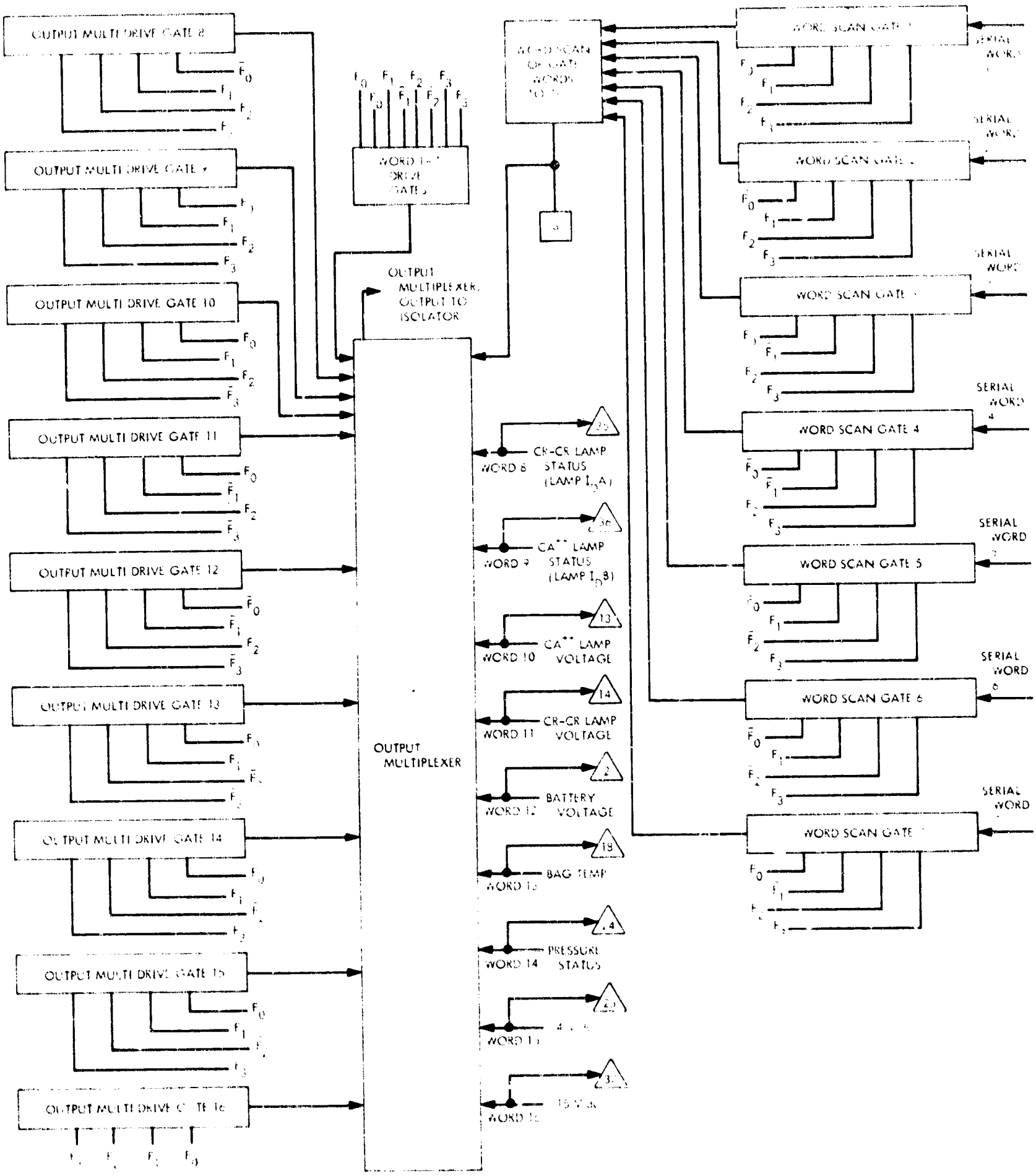


Fig. D-8. Data-handling system, data output

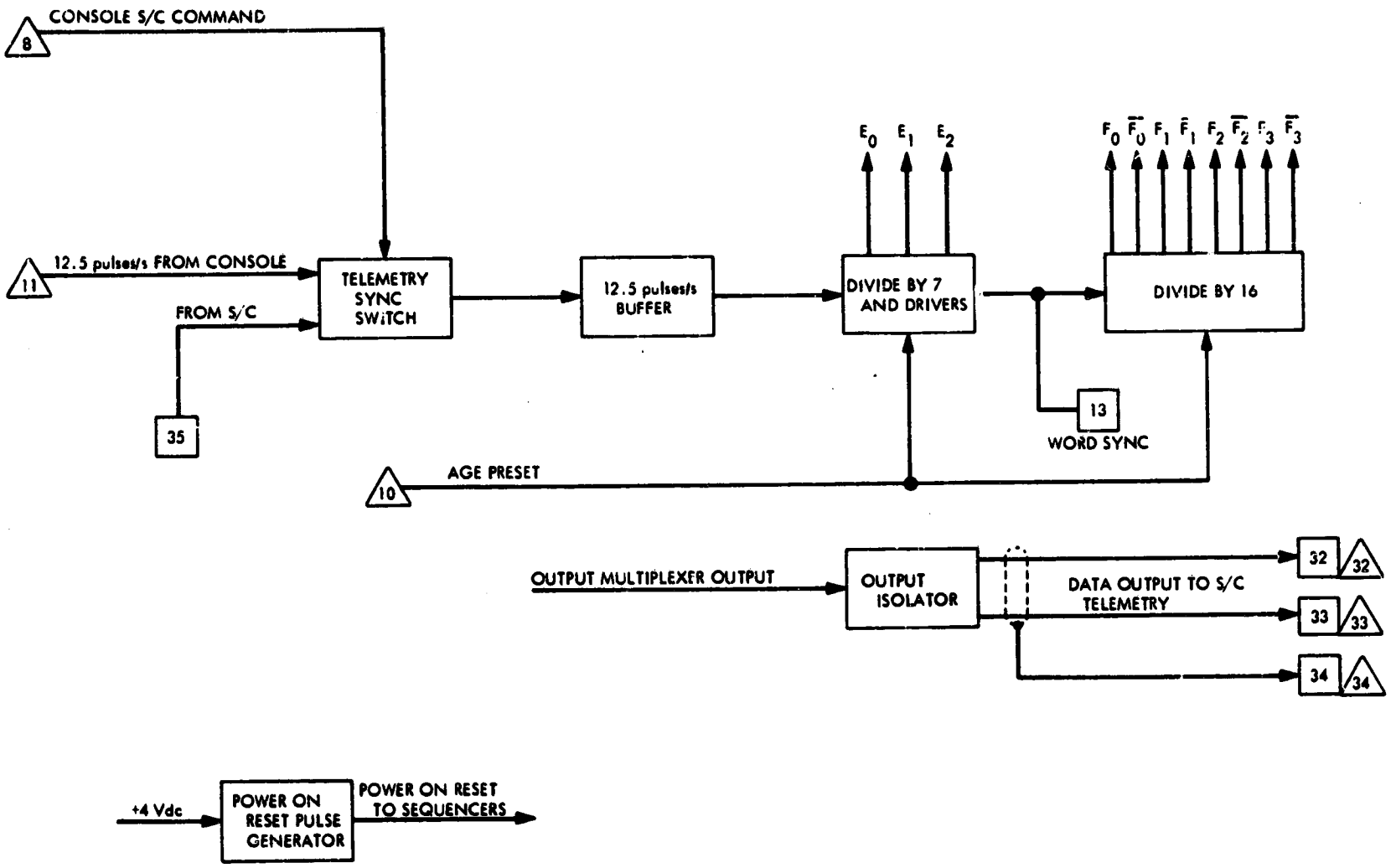


Fig. D-9. Data-handling system, clock

2

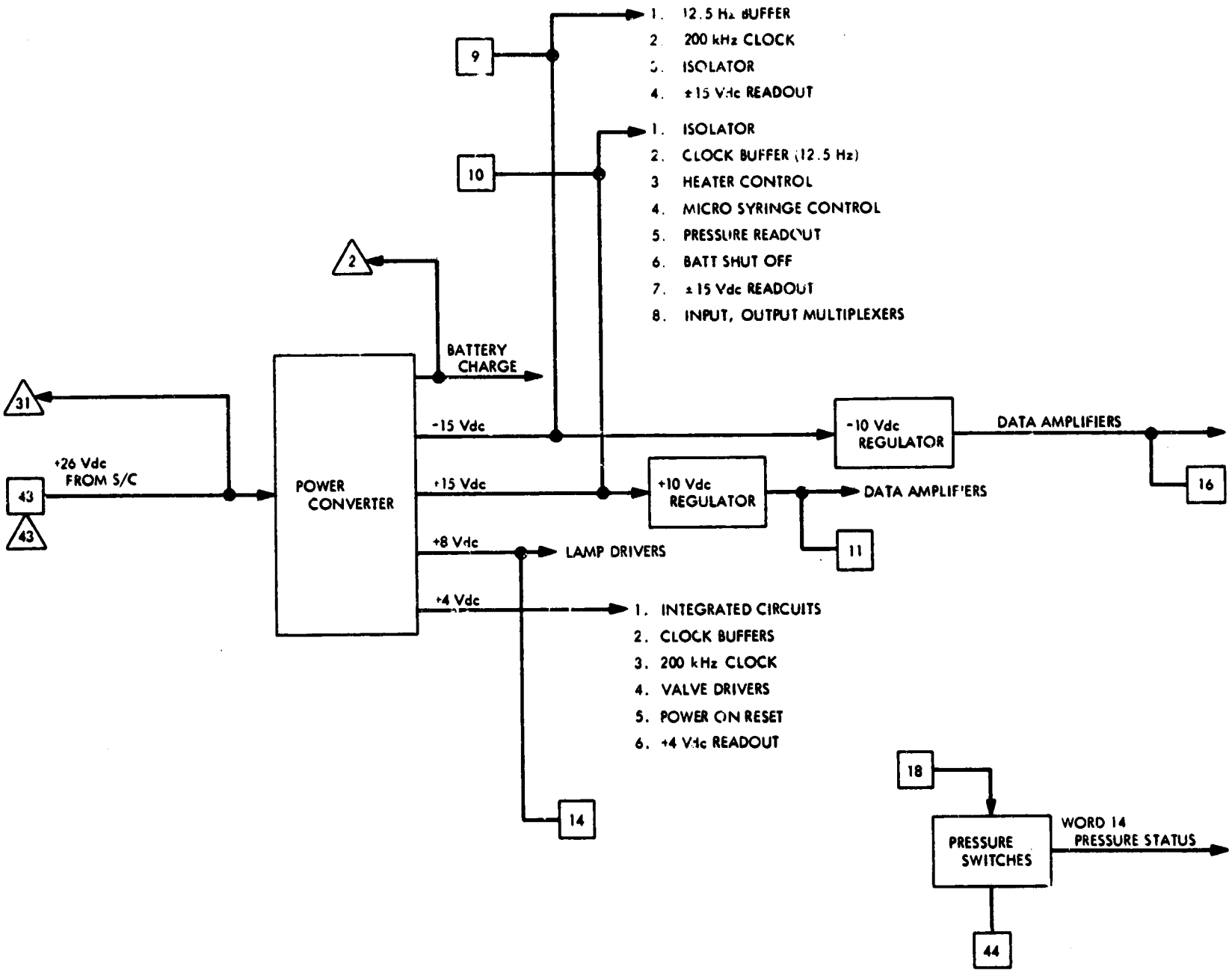


Fig. D-10. Power supply

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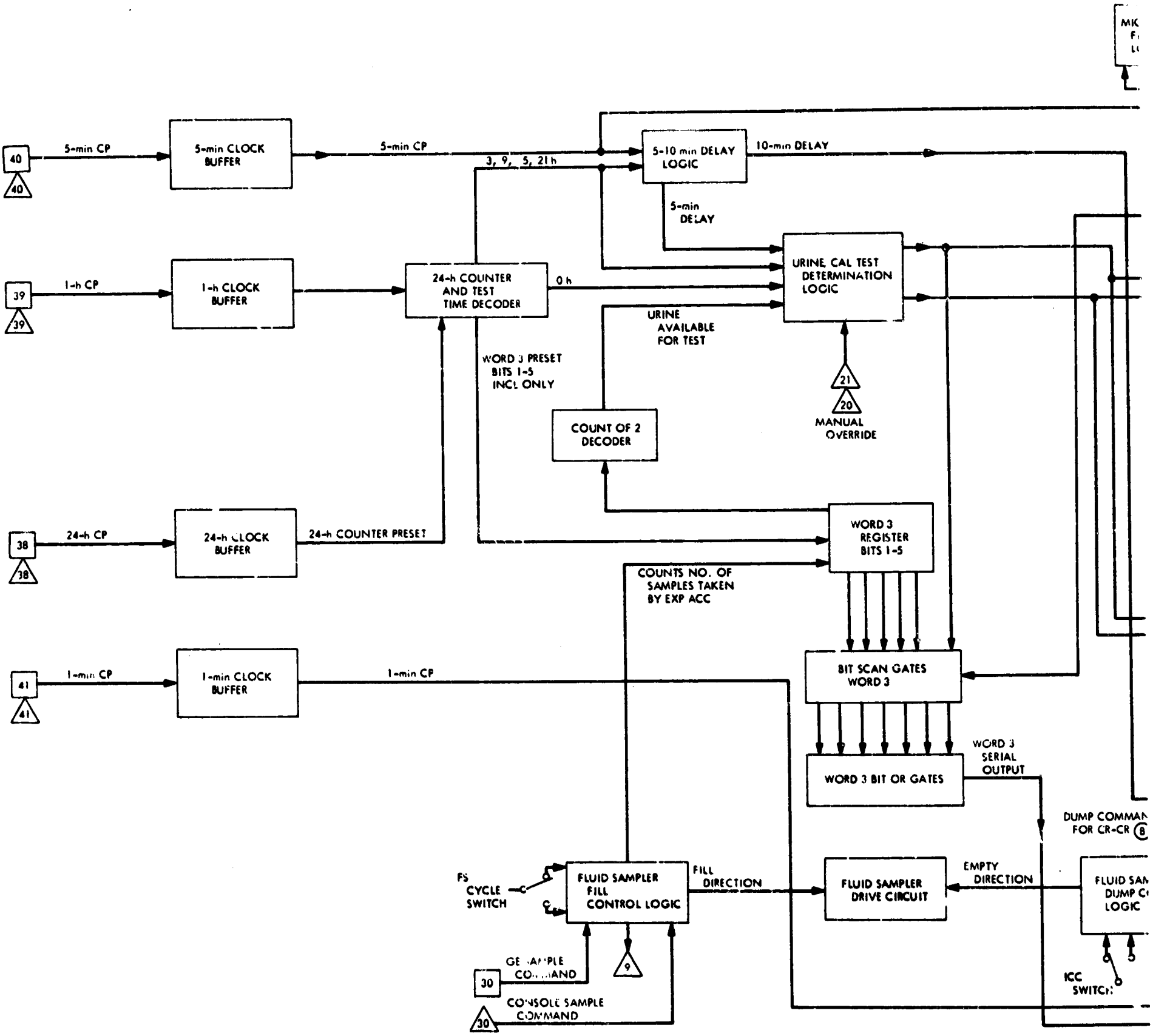
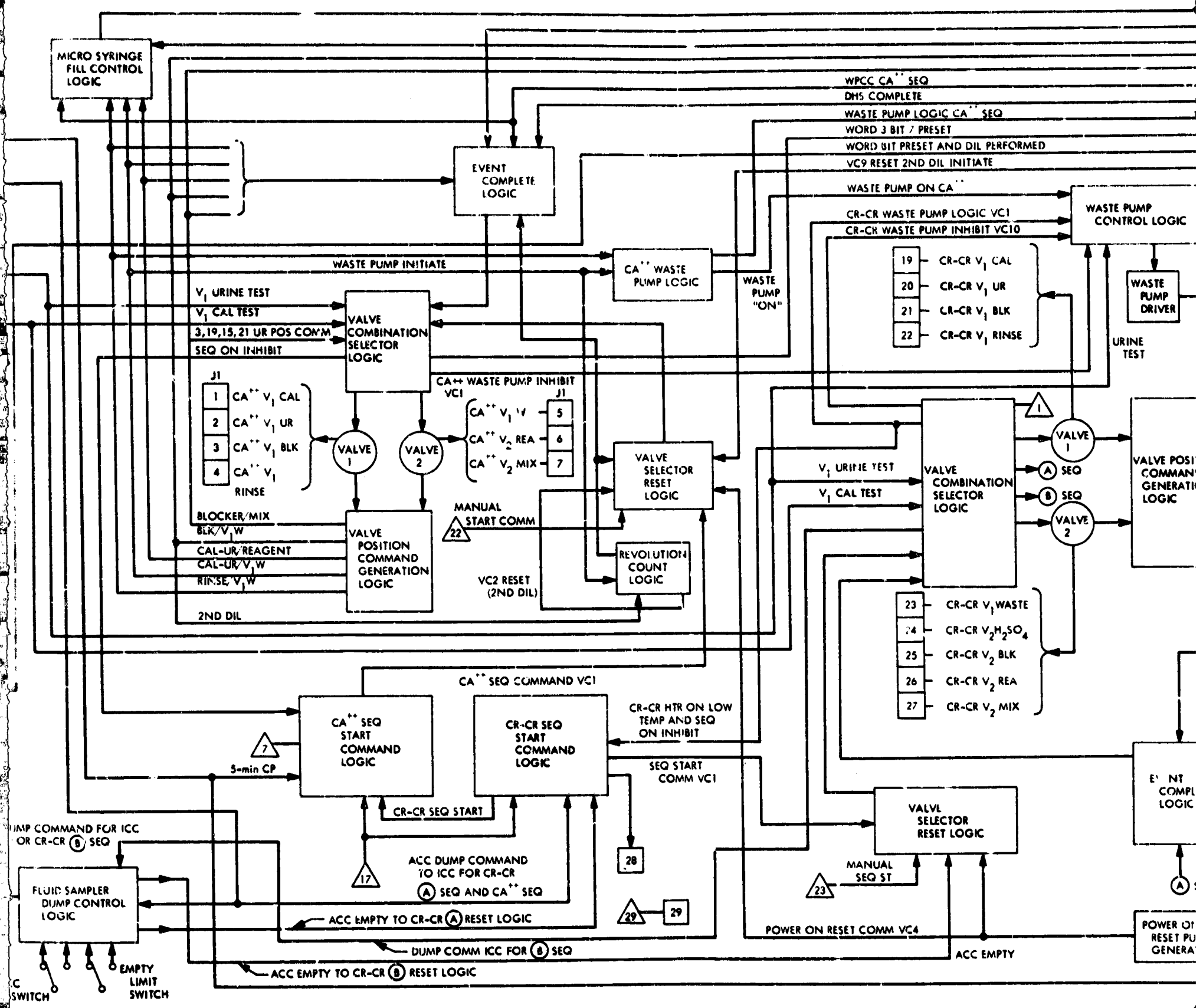
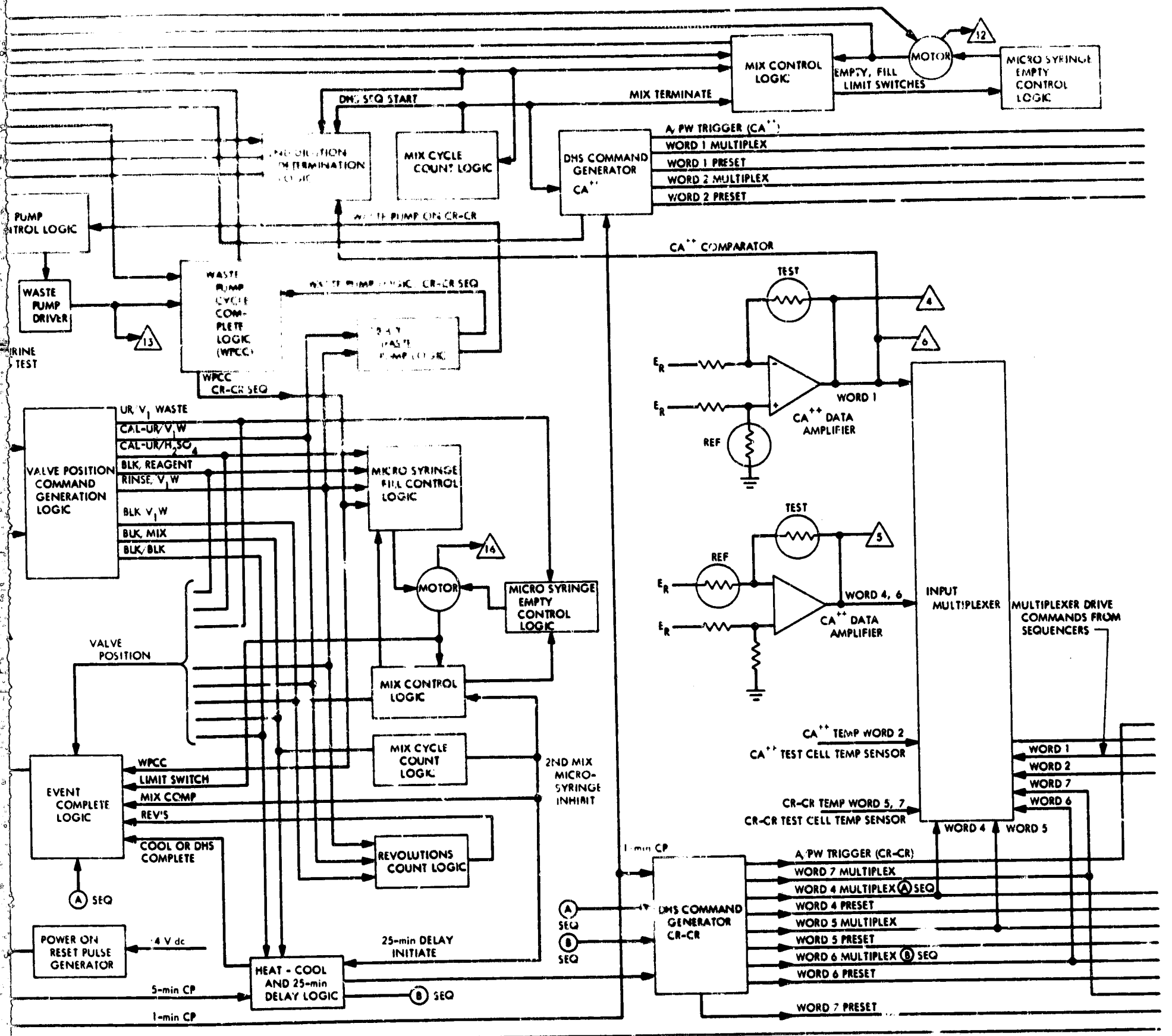


FOLDOUT FRAME 1



FOLDOUT FRAME 2


MIX CONTROL LOGIC
MOTOR
MICRO SYRINGE EMPTY CONTROL LOGIC
EMPTY, FILL LIMIT SWITCHES
MIX TERMINATE
DMS SEQ START
MIX CYCLE COUNT LOGIC
DMS COMMAND GENERATOR CA++
A/PW TRIGGER (CA++)
WORD 1 MULTIPLEX
WORD 1 PRESET
WORD 2 MULTIPLEX
WORD 2 PRESET
PUMP CONTROL LOGIC
WASTE PUMP DRIVER
WASTE PUMP CYCLE COMPLETE LOGIC (WPCC)
CA++ COMPARATOR
TEST
REF
WORD 1
CA++ DATA AMPLIFIER
WORD 4, 6
WORD 5
INPUT MULTIPLEXER
MULTIPLEXER DRIVE COMMANDS FROM SEQUENCERS
VALVE POSITION COMMAND GENERATION LOGIC
UR, V1 WASTE
CAL-UR/V1W
CAL-UR/H2SO4
BLK, REAGENT
RINSE, V1W
BLK V1W
BLK, MIX
BLK/BLK
MICRO SYRINGE FILL CONTROL LOGIC
MOTOR
MICRO SYRINGE EMPTY CONTROL LOGIC
VALVE POSITION
MIX CONTROL LOGIC
MIX CYCLE COUNT LOGIC
2ND MIX MICRO-SYRINGE INHIBIT
EVENT COMPLETE LOGIC
WPCC
LIMIT SWITCH
MIX COMP
REV'S
COOL OR DMS COMPLETE
REVOLUTIONS COUNT LOGIC
A SEQ
POWER ON RESET PULSE GENERATOR
+4 V dc
25-min DELAY INITIATE
HEAT - COOL AND 25-min DELAY LOGIC
B SEQ
5-min CP
1-min CP
CA++ TEMP WORD 2
CA++ TEST CELL TEMP SENSOR
CR-CR TEMP WORD 5, 7
CR-CR TEST CELL TEMP SENSOR
WORD 1
WORD 2
WORD 7
WORD 6
WORD 4
WORD 5
A SEQ
B SEQ
DMS COMMAND GENERATOR CR-CR
A/PW TRIGGER (CR-CR)
WORD 7 MULTIPLEX
WORD 4 MULTIPLEX A SEQ
WORD 4 PRESET
WORD 5 MULTIPLEX
WORD 5 PRESET
WORD 6 MULTIPLEX B SEQ
WORD 6 PRESET
WORD 7 PRESET

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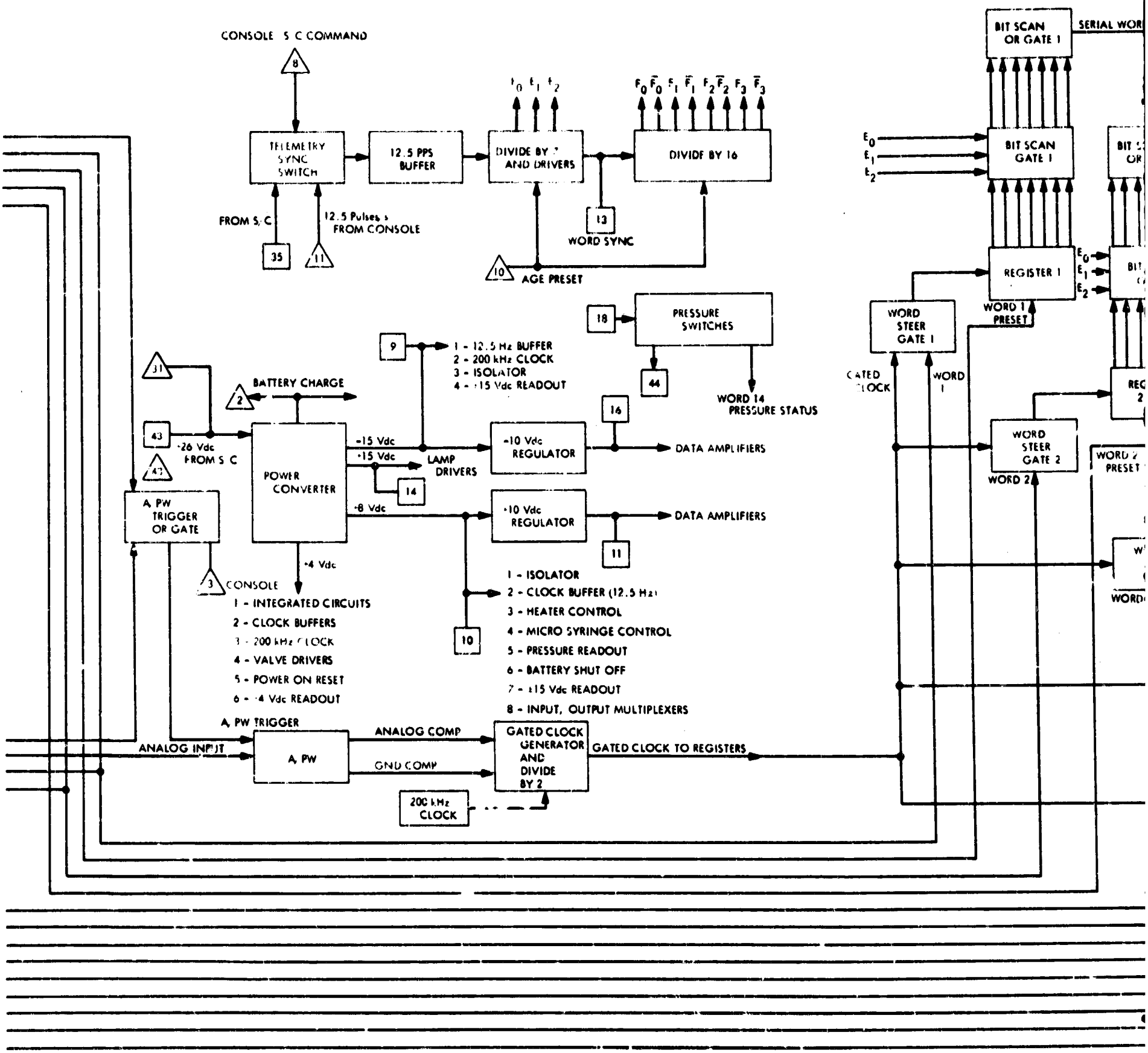

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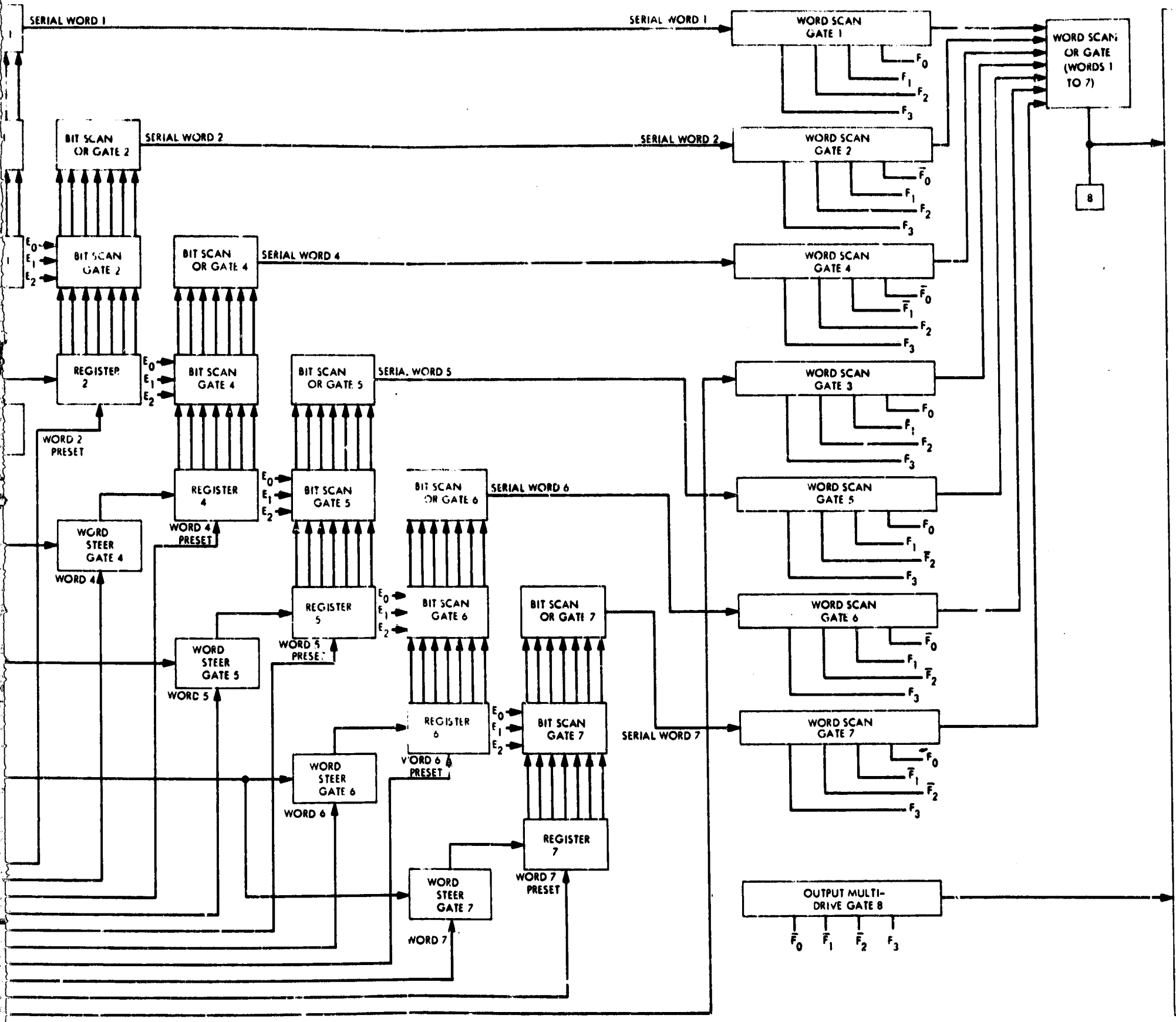

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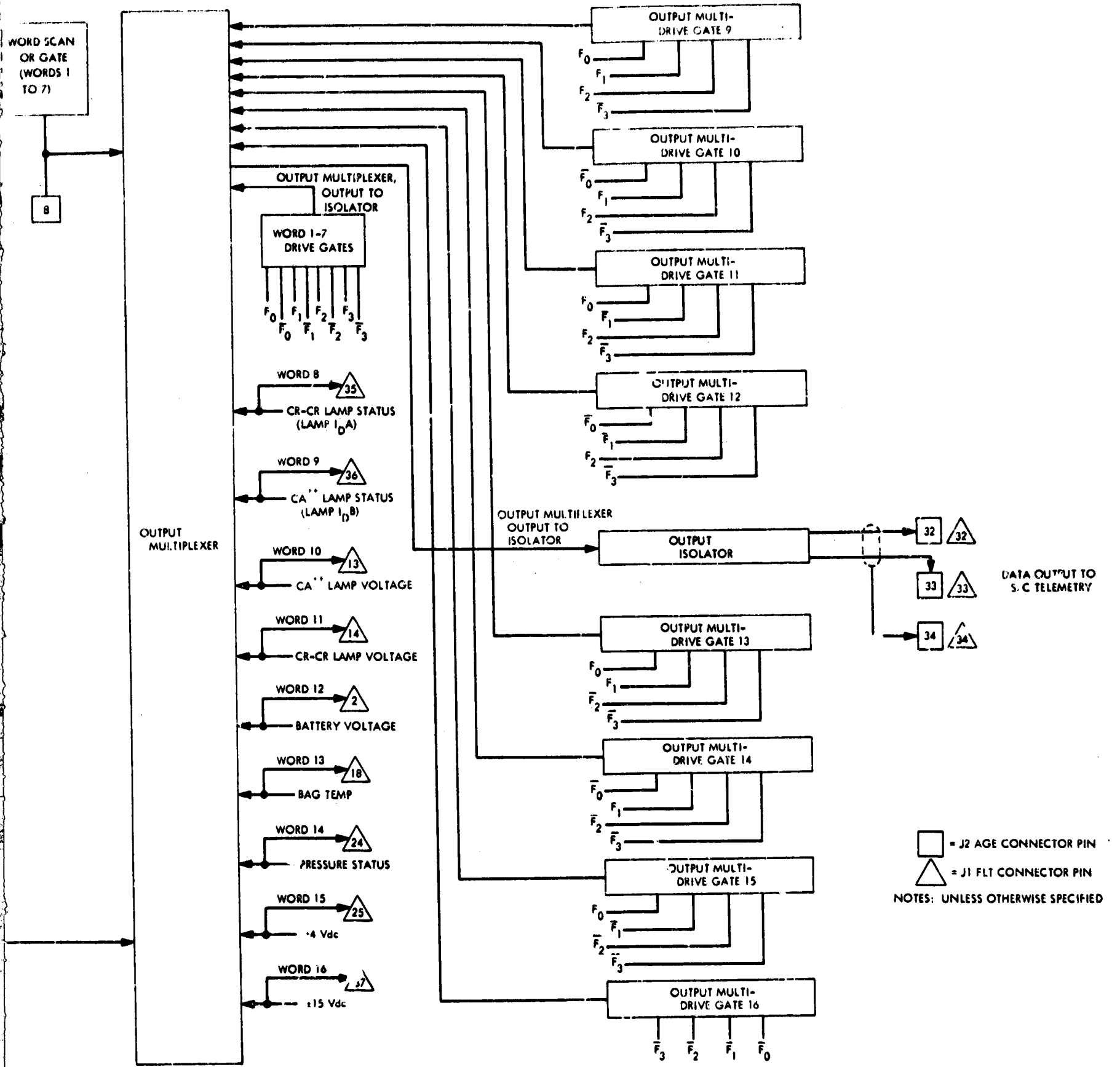

Fig. D-11. Electronics logic sequencer block diagram

Appendix E

Data-Handling System Calibration Curves

The curves in this appendix (Figs. E-1 through E-10) establish the calibration data for a typical experiment unit. These curves, when used with the information in Tables E-1 through E-3 and Appendix G, permit the reduction of the telemetered data (Fig. E-1) into science and engineering parameters as shown in Tables E-1 and E-2.

Table E-1. Example of Fig. E-1--science-stored data, words 1–7

Word	Binary readout	Octal equivalent	Telemetry input, V	Comments
1	1001101	131	3.515	10 mM Ca
2	1000101	121	3.203	33.2 C Ca test cell temperature
3	1001010	051	N/A	10 urine dumps, no dilution, urine (word 3 decoder, Table E-3)
4	1000110	061	1.953	12 mM creatine
5	1111101	137	3.750	33.0 C creatinine temperature
6	0000101	120	3.164	12 mM creatinine + 12 mM creatine at 75% conversion
7	0010011	144	3.945	32.7 C creatine emperature

Logical "1" = Q = +0.7 ± 0.3V; Logical "0" = $\bar{Q}$ = +4.0 ± 0.5 Vdc

Table E-2. Engineering and science data support—real-time data words, 8–16

Word	Analog readout	Telemetry inputs, V	Comments
8	1.50	1.58	Lamp current Cr Cr
9	1.45	1.54	Lamp current Ca
10	2.90	3.25	Lamp voltage Ca
11	2.85	3.20	Lamp voltage Cr-Cr
12	3.85	4.38	Battery voltage
13	2.30	2.57	T = 28.8 C = 89.6 F
14	0.30	0.02	P > 12.5 psia
15	3.67	4.15	4-V supply
16	2.25	2.50	15-V supply (normal)

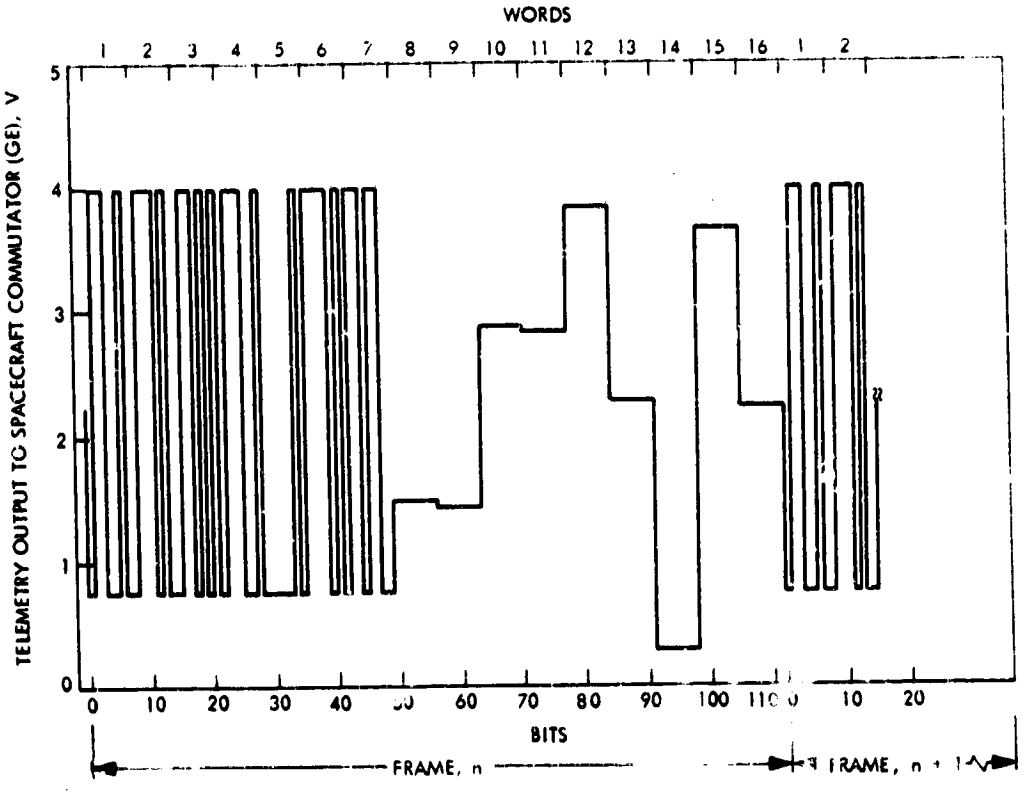

Fig. E-1. Telemetry data formut (typical)

Table E-3. Word 3 decoder

Octal readout	Binary conversion	Urine samples taken	Urine/ calibration test	Ca⁺⁺ second dilution	Octal readout	Binary conversion	Urine samples taken	Urine/ calibration test	Ca⁺⁺ second dilution
177	$ABCDEFG$	0	Urine	Yes	077	$ABCDEF\bar{G}$	0	Urine	No
000	$\bar{A}\bar{B}\bar{C}\bar{D}\bar{E}\bar{F}\bar{G}$	1	Calibration	No	100	$\bar{A}BCDEFG$	1	Calibration	Yes
001	$A\bar{B}\bar{C}\bar{D}\bar{E}\bar{F}\bar{G}$	2	Calibration	No	101	$A\bar{B}CDEFG$	2	Calibration	Yes
002	$\bar{A}\bar{B}\bar{C}\bar{D}\bar{E}\bar{F}\bar{G}$	3	Calibration	No	102	$\bar{A}\bar{B}CDEFG$	3	Calibration	Yes
003	$AB\bar{C}\bar{D}\bar{E}\bar{F}\bar{G}$	4	Calibration	No	103	$AB\bar{C}DEFG$	4	Calibration	Yes
004	$\bar{A}\bar{B}C\bar{D}\bar{E}\bar{F}\bar{G}$	5	Calibration	No	104	$\bar{A}\bar{B}C\bar{D}EFG$	5	Calibration	Yes
005	$A\bar{B}C\bar{D}\bar{E}\bar{F}\bar{G}$	6	Calibration	No	105	$A\bar{B}C\bar{D}EFG$	6	Calibration	Yes
006	$\bar{A}BC\bar{D}\bar{E}\bar{F}\bar{G}$	7	Calibration	No	106	$\bar{A}BC\bar{D}EFG$	7	Calibration	Yes
007	$ABC\bar{D}\bar{E}\bar{F}\bar{G}$	8	Calibration	No	107	$ABC\bar{D}EFG$	8	Calibration	Yes
010	$\bar{A}\bar{B}\bar{C}D\bar{E}\bar{F}\bar{G}$	9	Calibration	No	110	$\bar{A}\bar{B}\bar{C}DEFG$	9	Calibration	Yes
011	$A\bar{B}\bar{C}D\bar{E}\bar{F}\bar{G}$	10	Calibration	No	111	$A\bar{B}\bar{C}DEFG$	10	Calibration	Yes
012	$\bar{A}B\bar{C}D\bar{E}\bar{F}\bar{G}$	11	Calibration	No	112	$\bar{A}B\bar{C}DEFG$	11	Calibration	Yes
013	$AB\bar{C}D\bar{E}\bar{F}\bar{G}$	12	Calibration	No	113	$AB\bar{C}DEFG$	12	Calibration	Yes
014	$\bar{A}\bar{B}CD\bar{E}\bar{F}\bar{G}$	13	Calibration	No	114	$\bar{A}\bar{B}CDEFG$	13	Calibration	Yes
015	$A\bar{B}CD\bar{E}\bar{F}\bar{G}$	14	Calibration	No	115	$A\bar{B}CDEFG$	14	Calibration	Yes
016	$\bar{A}BCD\bar{E}\bar{F}\bar{G}$	15	Calibration	No	116	$\bar{A}BCDEFG$	15	Calibration	Yes
037	$ABCDE\bar{F}\bar{G}$	0	Calibration	No	137	$ABCDE\bar{F}G$	0	Calibration	Yes
040	$\bar{A}\bar{B}\bar{C}\bar{D}\bar{E}F\bar{G}$	1	Urine	No	140	$\bar{A}\bar{B}\bar{C}\bar{D}\bar{E}FG$	1	Urine	Yes
041	$A\bar{B}\bar{C}\bar{D}\bar{E}F\bar{G}$	2	Urine	No	141	$A\bar{B}\bar{C}\bar{D}\bar{E}FG$	2	Urine	Yes
042	$\bar{A}B\bar{C}\bar{D}\bar{E}F\bar{G}$	3	Urine	No	142	$\bar{A}B\bar{C}\bar{D}\bar{E}FG$	3	Urine	Yes
043	$AB\bar{C}\bar{D}\bar{E}F\bar{G}$	4	Urine	No	143	$AB\bar{C}\bar{D}\bar{E}FG$	4	Urine	Yes
044	$\bar{A}\bar{B}C\bar{D}\bar{E}F\bar{G}$	5	Urine	No	144	$\bar{A}\bar{B}C\bar{D}\bar{E}FG$	5	Urine	Yes
045	$A\bar{B}C\bar{D}\bar{E}F\bar{G}$	6	Urine	No	145	$A\bar{B}C\bar{D}\bar{E}FG$	6	Urine	Yes
046	$\bar{A}BC\bar{D}\bar{E}F\bar{G}$	7	Urine	No	146	$\bar{A}BC\bar{D}\bar{E}FG$	7	Urine	Yes
047	$ABC\bar{D}\bar{E}F\bar{G}$	8	Urine	No	147	$ABC\bar{D}\bar{E}FG$	8	Urine	Yes
050	$\bar{A}\bar{B}\bar{C}D\bar{E}F\bar{G}$	9	Urine	No	150	$\bar{A}\bar{B}\bar{C}D\bar{E}FG$	9	Urine	Yes
051	$A\bar{B}\bar{C}D\bar{E}F\bar{G}$	10	Urine	No	151	$A\bar{B}\bar{C}D\bar{E}FG$	10	Urine	Yes
052	$\bar{A}B\bar{C}D\bar{E}F\bar{G}$	11	Urine	No	152	$\bar{A}B\bar{C}D\bar{E}FG$	11	Urine	Yes
053	$AB\bar{C}D\bar{E}F\bar{G}$	12	Urine	No	153	$AB\bar{C}D\bar{E}FG$	12	Urine	Yes
054	$\bar{A}\bar{B}CD\bar{E}F\bar{G}$	13	Urine	No	154	$\bar{A}\bar{B}CD\bar{E}FG$	13	Urine	Yes
055	$A\bar{B}CD\bar{E}F\bar{G}$	14	Urine	No	155	$A\bar{B}CD\bar{E}FG$	14	Urine	Yes
056	$\bar{A}BCD\bar{E}F\bar{G}$	15	Urine	No	156	$\bar{A}BCD\bar{E}FG$	15	Urine	Yes

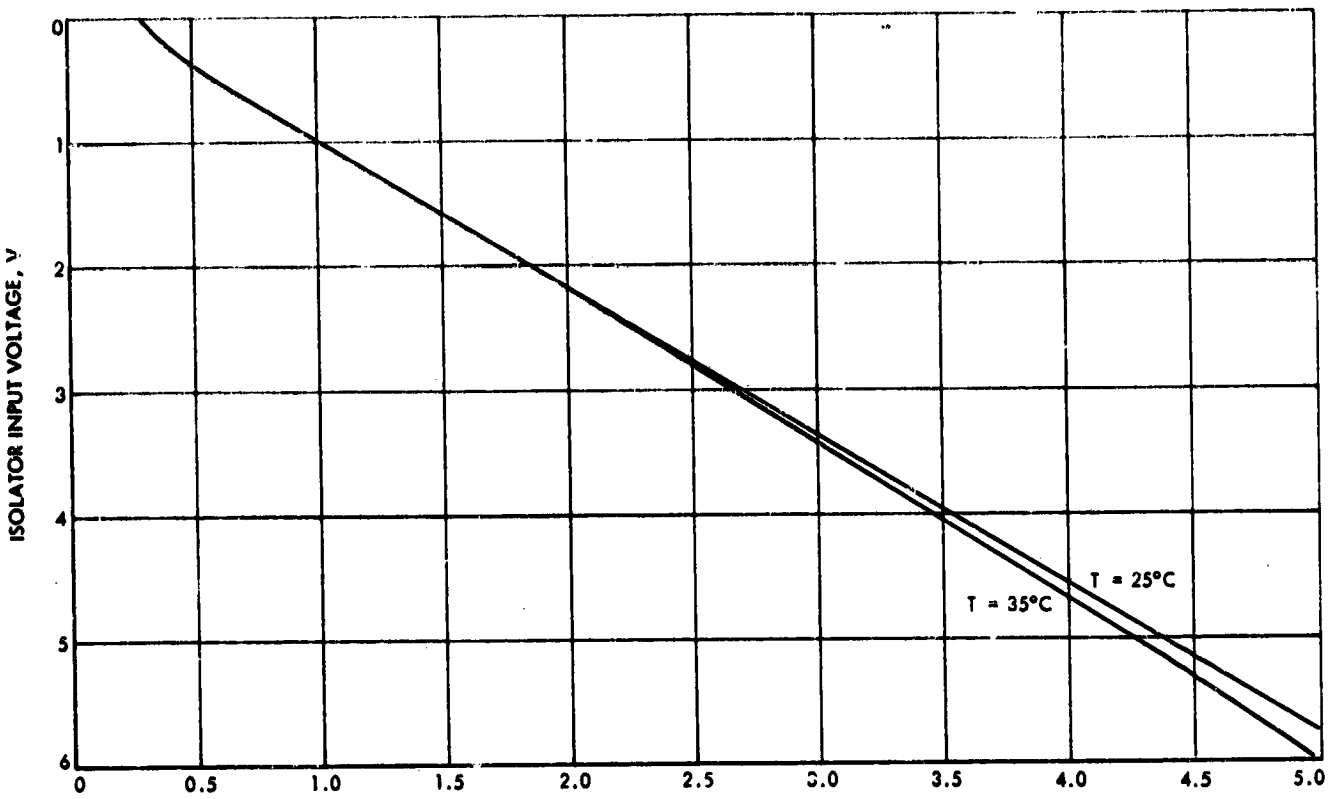

Fig. E-2. Isolator voltage transfer function

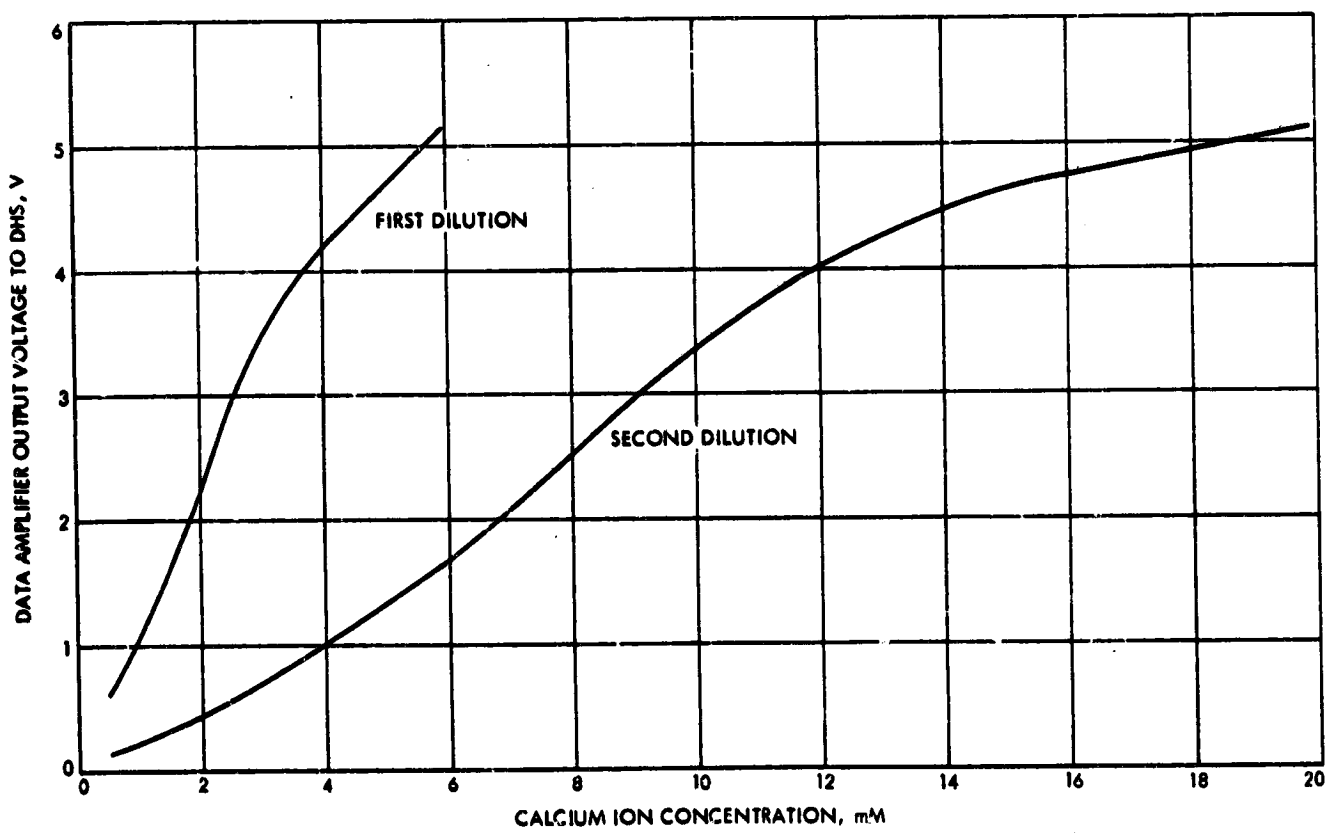

Fig. E-3. Calcium analyzer calibration curve—word 1

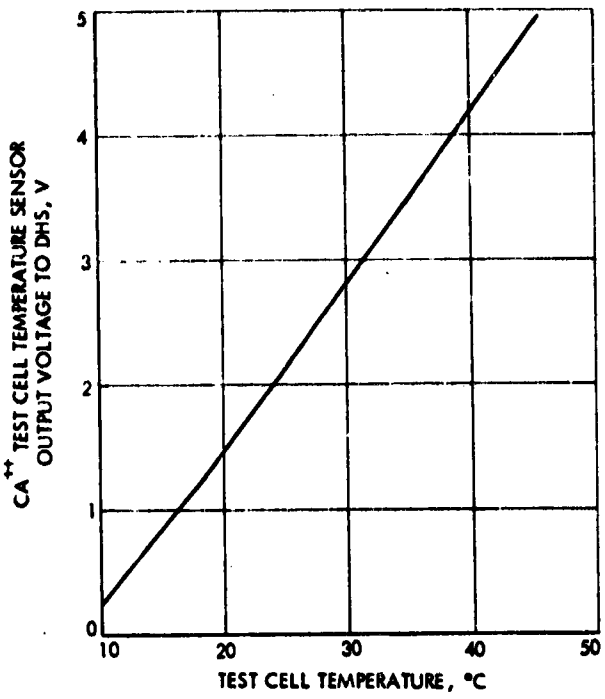

Fig. E-4. Calcium test cell temperature sensor calibration curve—word 2

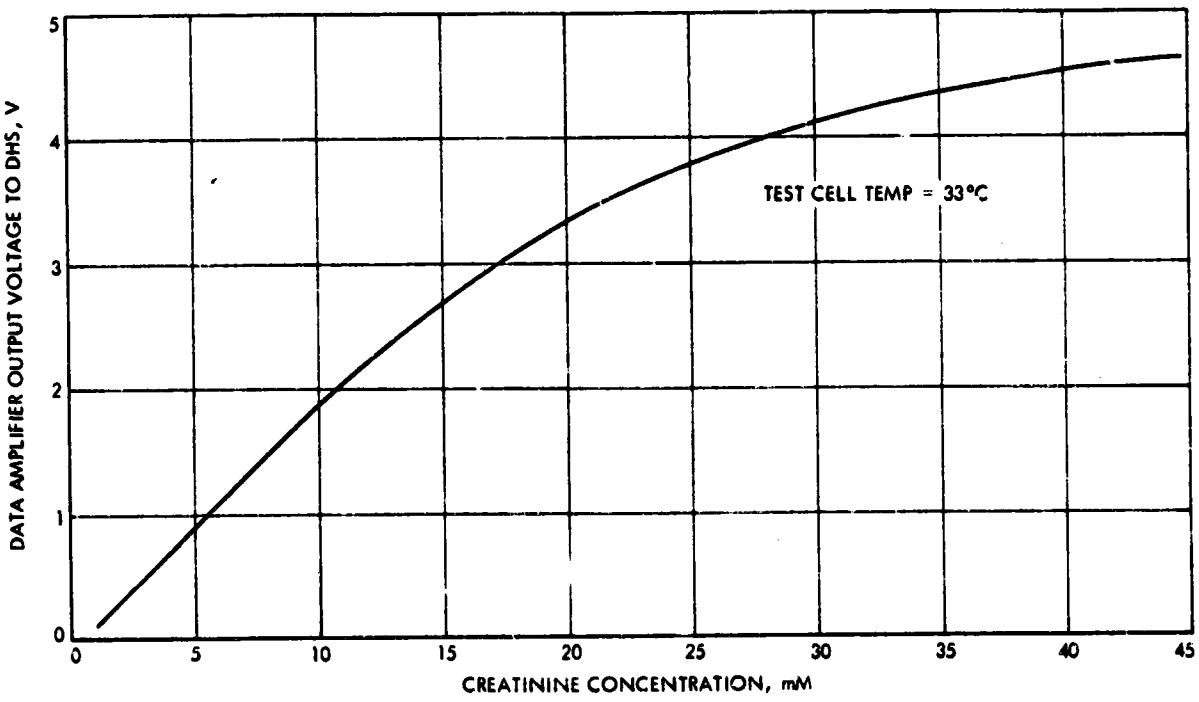

Fig. E-5. Creatinine analyzer calibration curve—word 4

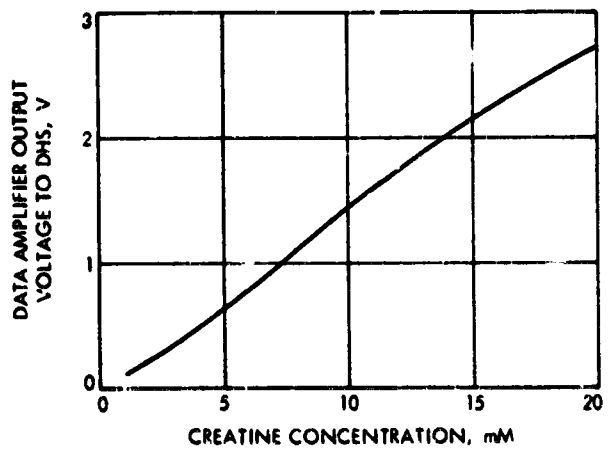

Fig. E-6. Creatine calibration in the creatinine analyzer—word 6

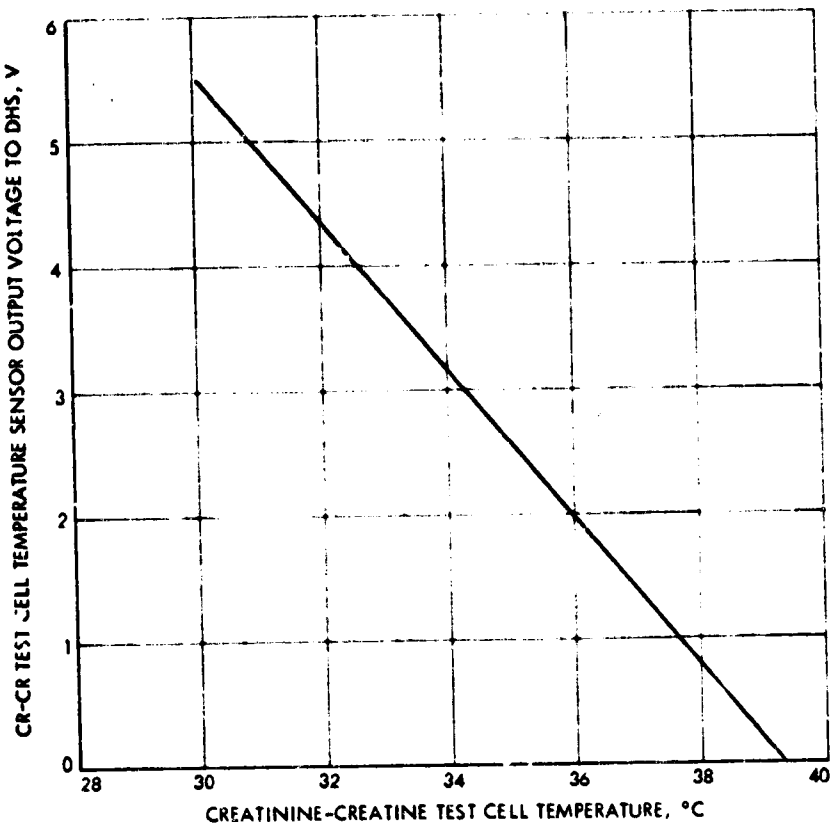

Fig. E-7. Creatinine analyzer temperature sensor calibration curve—words 5 and 7

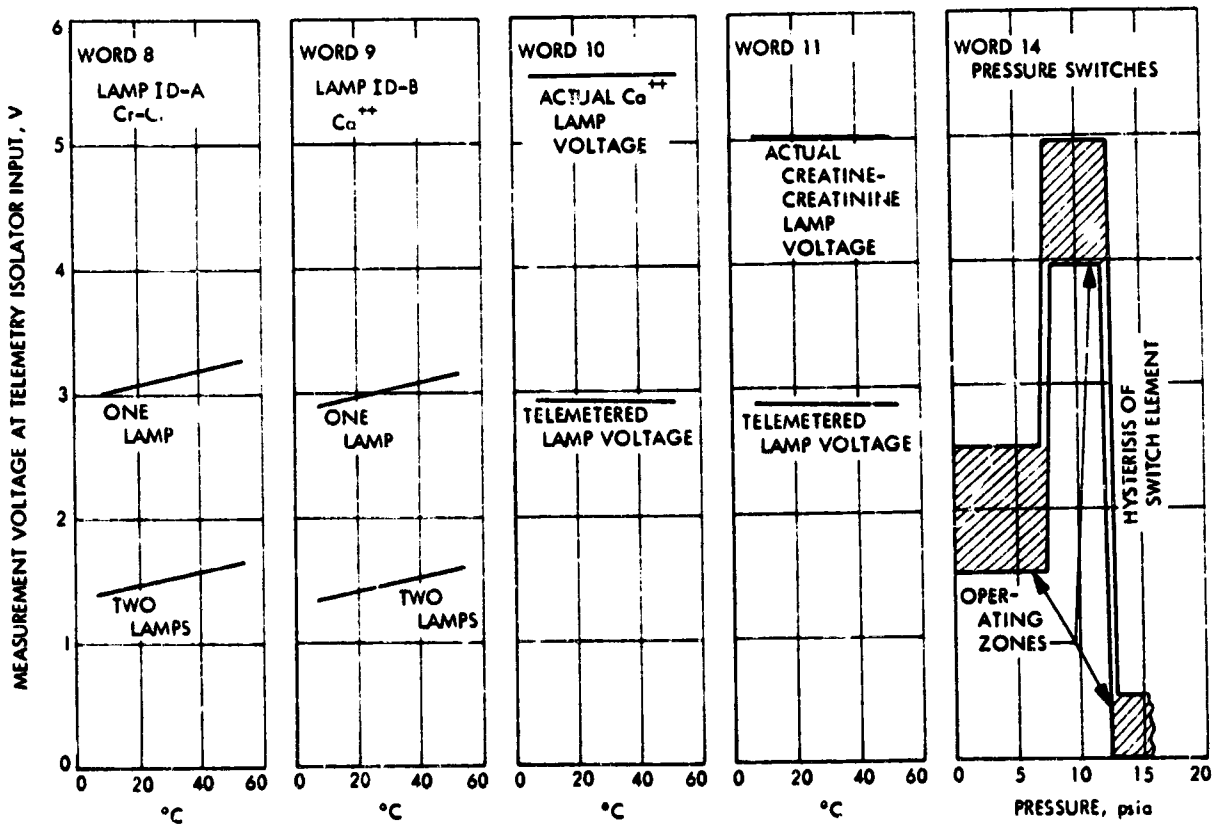

Fig. E-8. Engineering data words 8, 9, 10, 11, and 14 calibration

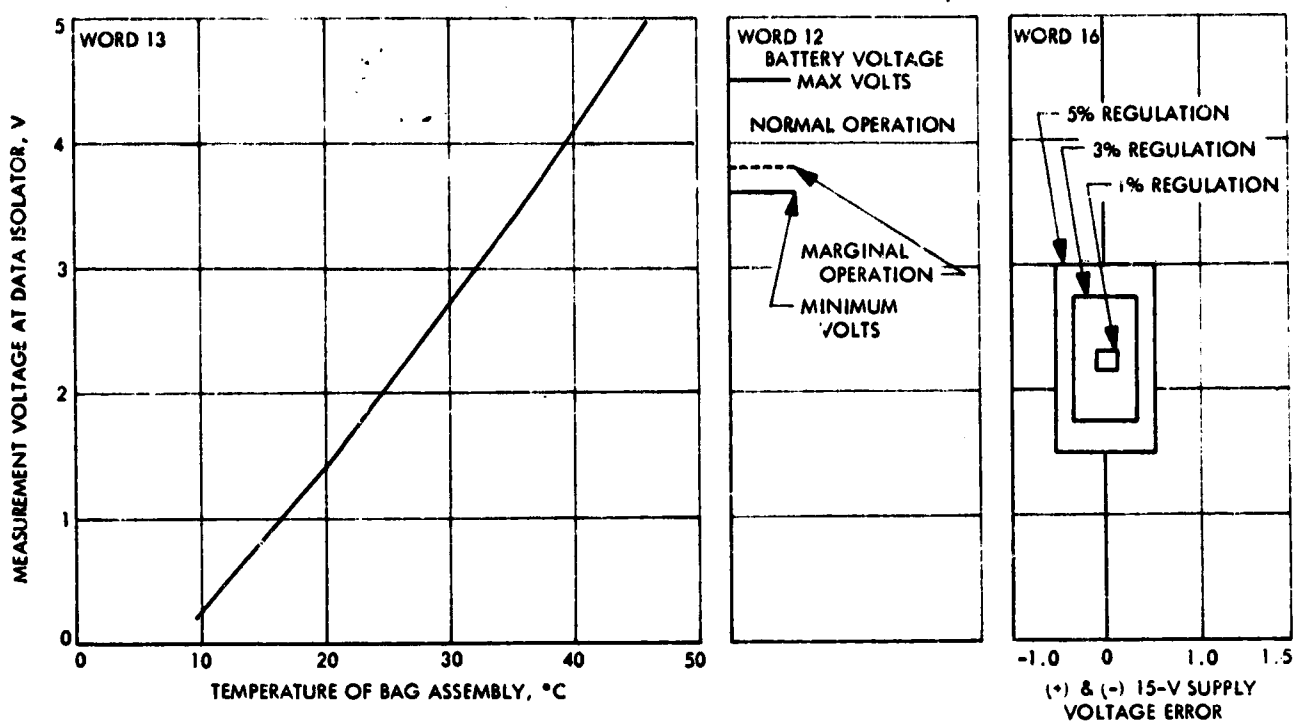

Fig. E-9. Engineering data words 12, 13, and 16 calibration

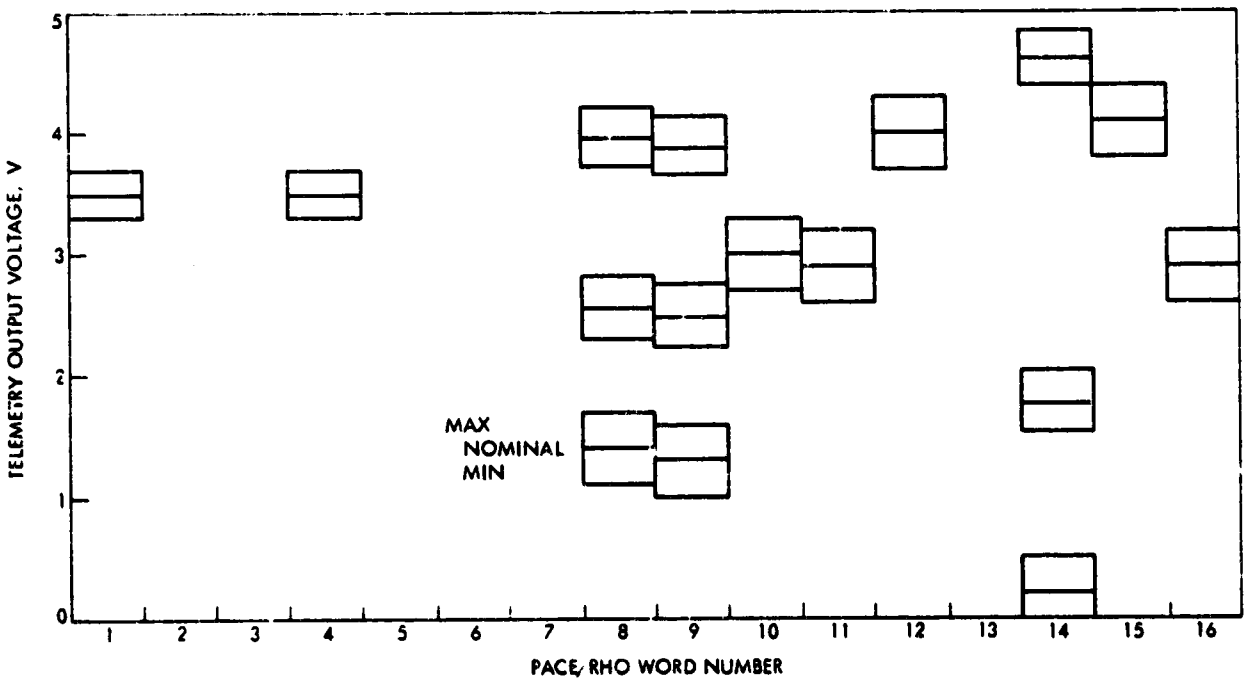

Fig. E-10. Range for normal mission performance

Appendix F

Ground-Support Equipment

Figures F-1 through F-3 show three pieces of ground-support equipment capable of simulating all spacecraft functions needed during systems and pre-launch tests.

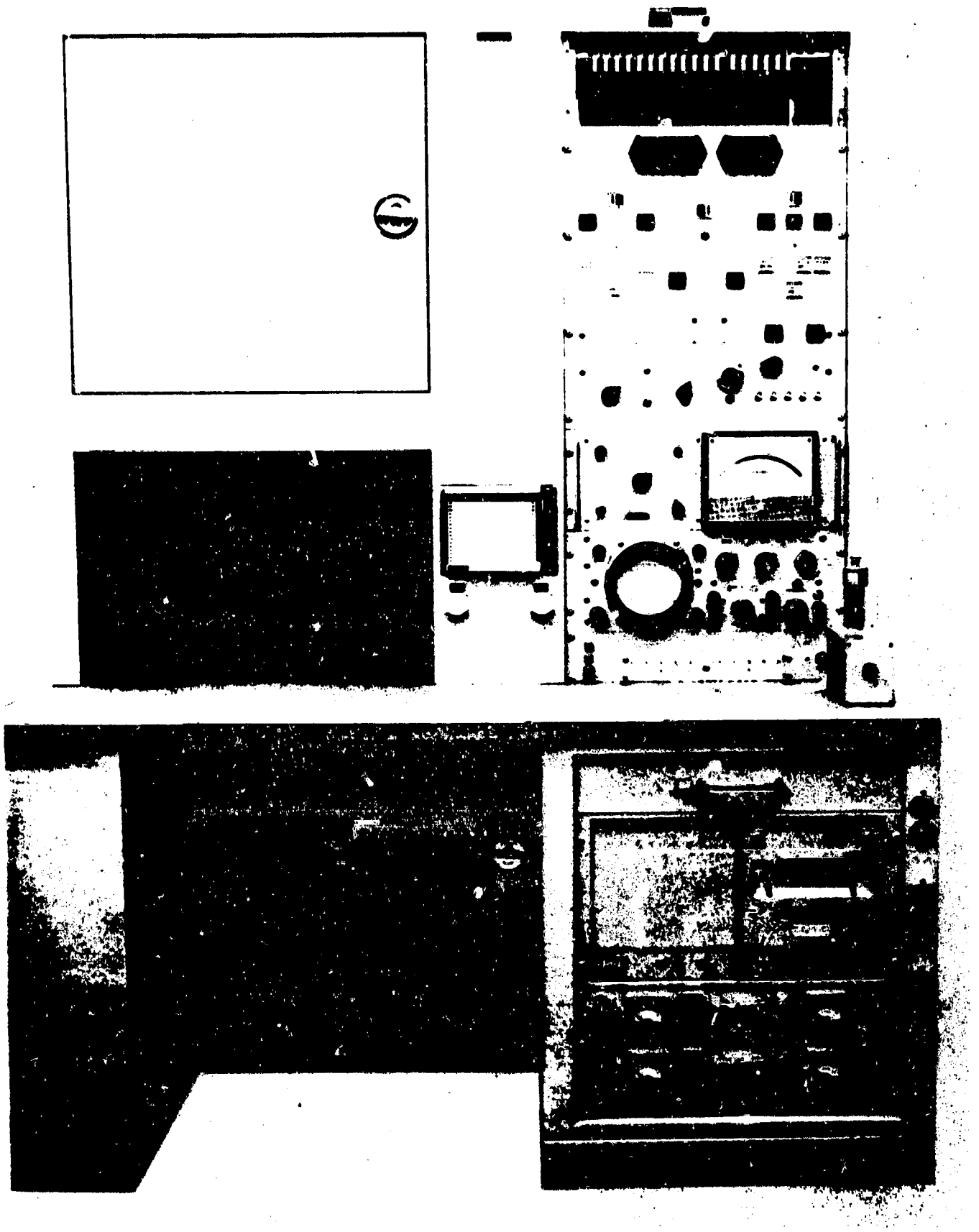

Fig. F-1. Front view of console showing Experiment Status Monitoring Panel, VTVM, oscilloscope, and strip chart recorder above the desk. Digital printer, power supplies and storage area are below the desk.

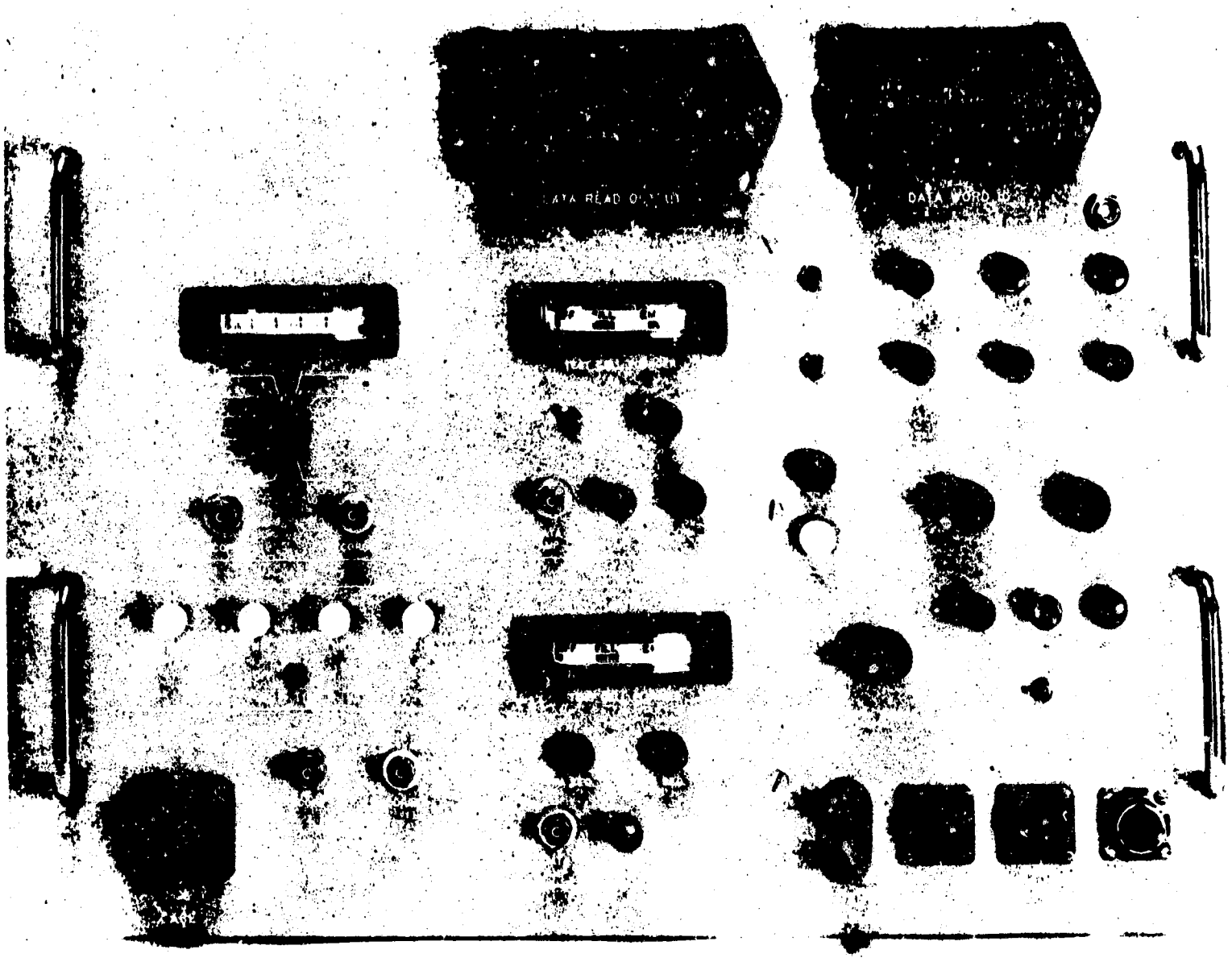

Fig. F-2. Portable Aerospace Ground Equipment (AGE) designed for self-contained battery operation to support the experiment package during field tests and checkout operations.

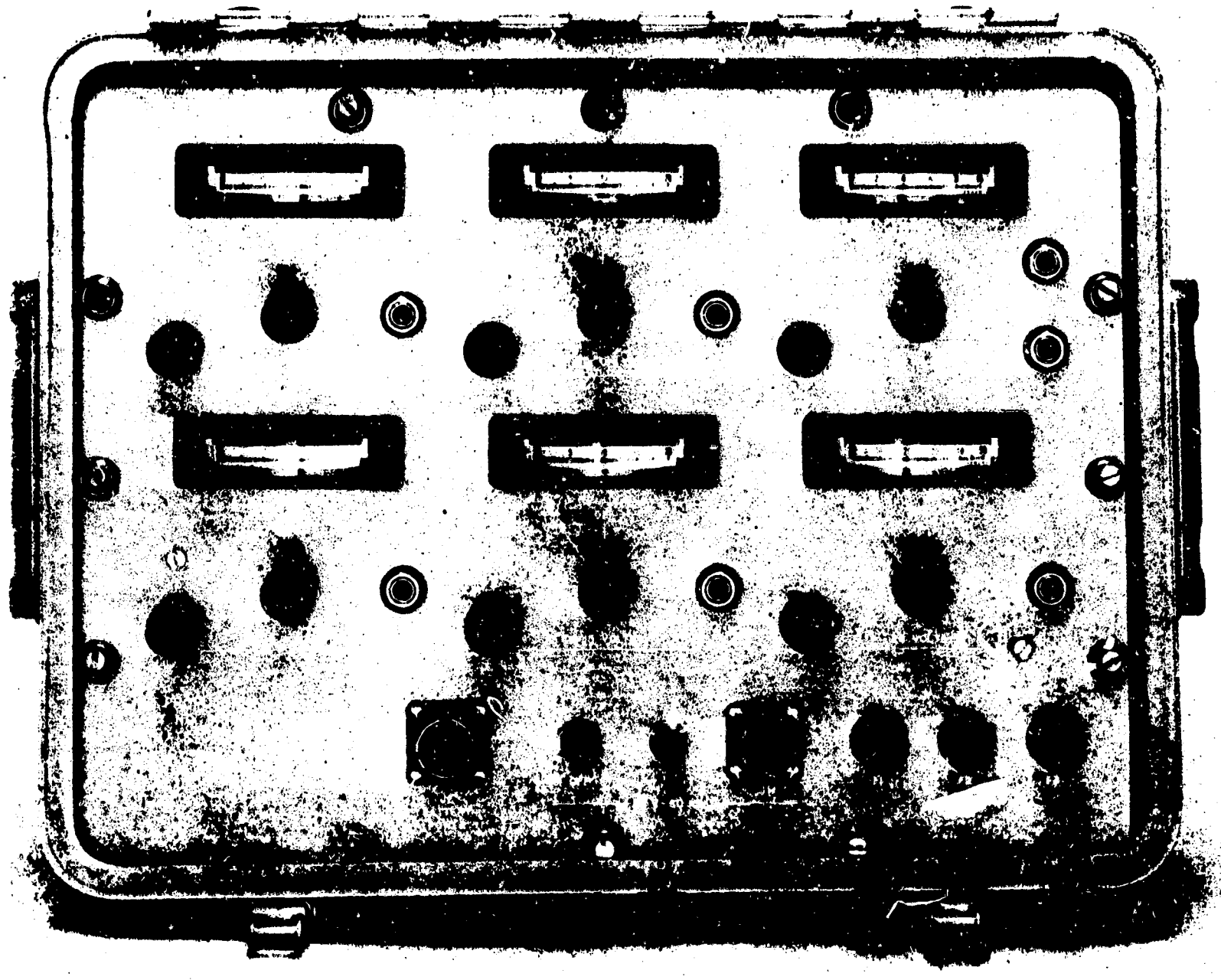

Fig. F-3. Gantry AGE battery pack.

Appendix G

Analog-To-Octal-To-Binary Conversion Tables

Table G-1 allows reduction of the binary-coded science data to be reduced to equivalent analog voltages for comparison to calibration curves and for reduction to scientific parameters. The octal equivalent columns are used to decode the octal data recorded by the ground-support equipment.

Table G-1. Conversion table[a]

Gate	Quantizing level	Binary inputs	Words 8–16 octal equivalent	Words 1–7 octal equivalent	Gate	Quantizing level	Binary inputs	Words 8–16 octal equivalent	Words 1–7 octal equivalent
1	0	$ABCDEFG$	0	177	44	1.679	$\bar{A}B\bar{C}D\bar{E}F\bar{G}$	53	52
2	0.03906	$\bar{A}BCDEFG$	1	0	45	1.718	$AB\bar{C}D\bar{E}F\bar{G}$	54	53
3	0.078[illegible]	$A\bar{B}CDEFG$	2	1	46	1.757	$\bar{A}BCD\bar{E}F\bar{G}$	55	54
4	0.1171	$\bar{A}\bar{B}CDEFG$	3	2	47	1.796	$A\bar{B}CD\bar{E}F\bar{G}$	56	55
5	0.1562	$AB\bar{C}DEFG$	4	3	48	1.835	$\bar{A}B\bar{C}D\bar{E}F\bar{G}$	57	56
6	0.1953	$\bar{A}B\bar{C}DEFG$	5	4	49	1.875	$AB\bar{C}D\bar{E}F\bar{G}$	60	57
7	0.2343	$A\bar{B}\bar{C}DEFG$	6	5	50	1.914	$\bar{A}\bar{B}\bar{C}DEF\bar{G}$	61	60
8	0.2734	$\bar{A}\bar{B}\bar{C}DEFG$	7	6	51	1.953	$A\bar{B}\bar{C}DEF\bar{G}$	62	61
9	0.3125	$ABCD\bar{E}FG$	10	7	52	1.992	$\bar{A}B\bar{C}DEF\bar{G}$	63	62
10	0.3515	$A\bar{B}CD\bar{E}FG$	11	10	53	2.031	$AB\bar{C}DEF\bar{G}$	64	63
11	0.39062	$\bar{A}BCD\bar{E}FG$	12	11	54	2.070	$\bar{A}B\bar{C}DEF\bar{G}$	65	64
12	0.4296	$\bar{A}\bar{B}CD\bar{E}FG$	13	12	55	2.109	$A\bar{B}CDEF\bar{G}$	66	65
13	0.4687	$AB\bar{C}D\bar{E}FG$	14	13	56	2.148	$\bar{A}B\bar{C}DEF\bar{G}$	67	66
14	0.5078	$\bar{A}B\bar{C}D\bar{E}FG$	15	14	57	2.187	$AB\bar{C}D\bar{E}F\bar{G}$	70	67
15	0.5468	$A\bar{B}CD\bar{E}FG$	16	15	58	2.226	$\bar{A}\bar{B}CDEF\bar{G}$	71	70
16	0.5859	$\bar{A}BCD\bar{E}FG$	17	16	59	2.265	$A\bar{B}CDEF\bar{G}$	72	71
17	0.6250	$ABCDE\bar{F}G$	20	17	60	2.304	$\bar{A}B\bar{C}DEF\bar{G}$	73	72
18	0.6640	$\bar{A}BCDE\bar{F}G$	21	20	61	2.343	$AB\bar{C}DEF\bar{G}$	74	73
19	0.7031	$A\bar{B}CDE\bar{F}G$	22	21	62	2.382	$\bar{A}\bar{B}CDEF\bar{G}$	75	74
20	0.7421	$\bar{A}\bar{B}CDE\bar{F}G$	23	22	63	2.421	$A\bar{B}CDEF\bar{G}$	76	75
21	0.7812	$AB\bar{C}DE\bar{F}G$	24	23	64	2.461	$\bar{A}BCDEF\bar{G}$	77	76
22	0.8203	$\bar{A}B\bar{C}DE\bar{F}G$	25	24	65	2.500	$ABCDEF\bar{G}$	100	77
23	0.8593	$A\bar{B}\bar{C}DE\bar{F}G$	26	25	66	2.539	$\bar{A}\bar{B}\bar{C}DEFG$	101	100
24	0.8984	$\bar{A}\bar{B}\bar{C}DE\bar{F}G$	27	26	67	2.578	$A\bar{B}\bar{C}DEFG$	102	101
25	0.9375	$ABCD\bar{E}\bar{F}G$	30	27	68	2.617	$\bar{A}B\bar{C}DEFG$	103	102
26	0.9765	$\bar{A}BCD\bar{E}\bar{F}G$	31	30	69	2.656	$AB\bar{C}DEFG$	104	103
27	1.0156	$A\bar{B}CD\bar{E}\bar{F}G$	32	31	70	2.695	$\bar{A}BCDEFG$	105	104
28	1.0546	$\bar{A}\bar{B}CD\bar{E}\bar{F}G$	33	32	71	2.734	$A\bar{B}CDEFG$	106	105
29	1.0937	$AB\bar{C}D\bar{E}\bar{F}G$	34	33	72	2.773	$\bar{A}\bar{B}CDEFG$	107	106
30	1.132	$\bar{A}BCD\bar{E}\bar{F}G$	35	34	73	2.812	$ABCDEFG$	110	107
31	1.171	$A\bar{B}CD\bar{E}\bar{F}G$	36	35	74	2.851	$\bar{A}\bar{B}\bar{C}DEFG$	111	110
32	1.210	$\bar{A}\bar{B}CD\bar{E}\bar{F}G$	37	36	75	2.890	$A\bar{B}\bar{C}DEFG$	112	111
33	1.250	$ABCDE\bar{F}\bar{G}$	40	37	76	2.929	$\bar{A}B\bar{C}DEFG$	113	112
34	1.289	$\bar{A}BCDE\bar{F}\bar{G}$	41	40	77	2.968	$AB\bar{C}DEFG$	114	113
35	1.328	$A\bar{B}CDE\bar{F}\bar{G}$	42	41	78	3.007	$\bar{A}\bar{B}CDEFG$	115	114
36	1.367	$\bar{A}\bar{B}CDE\bar{F}\bar{G}$	43	42	79	3.046	$A\bar{B}CDEFG$	116	115
37	1.406	$AB\bar{C}D\bar{E}\bar{F}\bar{G}$	44	43	80	3.085	$\bar{A}BCDEFG$	117	116
38	1.445	$\bar{A}B\bar{C}D\bar{E}\bar{F}\bar{G}$	45	44	81	3.125	$ABCDEFG$	120	117
39	1.484	$A\bar{B}\bar{C}D\bar{E}\bar{F}\bar{G}$	46	45	82	3.164	$\bar{A}\bar{B}\bar{C}DEFG$	121	120
40	1.523	$\bar{A}\bar{B}\bar{C}D\bar{E}\bar{F}\bar{G}$	47	46	83	3.203	$A\bar{B}\bar{C}DEFG$	122	121
41	1.562	$ABCD\bar{E}\bar{F}\bar{G}$	50	47	84	3.242	$\bar{A}B\bar{C}DEFG$	123	122
42	1.601	$\bar{A}BCD\bar{E}\bar{F}\bar{G}$	51	50	85	3.281	$AB\bar{C}DEFG$	124	123
43	1.640	$A\bar{B}CD\bar{E}\bar{F}\bar{G}$	52	51	86	3.320	$\bar{A}\bar{B}\bar{C}DEFG$	125	124

[a] Q = logical 1 $\approx$ 0 V.
$\bar{Q}$ = logical 0 $\approx$ +2.5 V.

Table G-1 (contd)

Gate	Quantizing level	Binary inputs	Words 8–16 octal equivalent	Words 1–7 octal equivalent	Gate	Quantizing level	Binary inputs	Words 8–16 octal equivalent	Words 1–7 octal equivalent
87	3.359	$\bar{A}B\bar{C}\bar{D}EFG$	126	125	108	4.179	$\bar{A}B\bar{C}\bar{D}EFG$	153	152
88	3.398	$\bar{A}BC\bar{D}\bar{E}FG$	127	126	109	4.218	$AB\bar{C}\bar{D}\bar{E}FG$	154	153
89	3.437	$ABC\bar{D}\bar{E}FG$	130	127	110	4.257	$\bar{A}\bar{B}CD\bar{E}FG$	155	154
90	3.476	$\bar{A}\bar{B}\bar{C}DEFG$	131	130	111	4.296	$A\bar{B}CD\bar{E}FG$	156	155
91	3.515	$A\bar{B}\bar{C}DEFG$	132	131	112	4.335	$\bar{A}BCD\bar{E}FG$	157	156
92	3.554	$\bar{A}B\bar{C}DEFG$	133	132	113	4.375	$ABCD\bar{E}FG$	160	157
93	3.593	$AB\bar{C}DEFG$	134	133	114	4.414	$\bar{A}\bar{B}\bar{C}DEFG$	161	160
94	3.632	$\bar{A}\bar{B}CDEFG$	135	134	115	4.453	$A\bar{B}\bar{C}DEFG$	162	161
95	3.671	$A\bar{B}CDEFG$	136	135	116	4.492	$\bar{A}B\bar{C}DEFG$	163	162
96	3.710	$\bar{A}BCDEFG$	137	136	117	4.531	$AB\bar{C}DEFG$	164	163
97	3.750	$ABCDEFG$	140	137	118	4.570	$\bar{A}\bar{B}CDEFG$	165	164
98	3.789	$\bar{A}\bar{B}\bar{C}\bar{D}\bar{E}\bar{F}G$	141	140	119	4.609	$A\bar{B}CDEFG$	166	165
99	3.828	$A\bar{B}\bar{C}\bar{D}\bar{E}\bar{F}G$	142	141	120	4.648	$\bar{A}BCDEFG$	167	166
100	3.867	$\bar{A}B\bar{C}\bar{D}\bar{E}\bar{F}G$	143	142	121	4.687	$ABCDEFG$	170	167
101	3.906	$AB\bar{C}\bar{D}\bar{E}\bar{F}G$	144	143	122	4.726	$\bar{A}\bar{B}\bar{C}\bar{D}\bar{E}\bar{F}\bar{G}$	171	170
102	3.945	$\bar{A}\bar{B}C\bar{D}\bar{E}\bar{F}G$	145	144	123	4.765	$A\bar{B}\bar{C}\bar{D}\bar{E}\bar{F}\bar{G}$	172	171
103	3.984	$A\bar{B}C\bar{D}\bar{E}\bar{F}G$	146	145	124	4.804	$\bar{A}B\bar{C}\bar{D}\bar{E}\bar{F}\bar{G}$	173	172
104	4.023	$\bar{A}BC\bar{D}\bar{E}\bar{F}G$	147	146	125	4.843	$AB\bar{C}\bar{D}\bar{E}\bar{F}\bar{G}$	174	173
105	4.062	$ABC\bar{D}\bar{E}\bar{F}G$	150	147	126	4.882	$\bar{A}\bar{B}C\bar{D}\bar{E}\bar{F}\bar{G}$	175	174
106	4.101	$\bar{A}\bar{B}\bar{C}DEFG$	151	150	127	4.921	$A\bar{B}CDEFG$	176	175
107	4.140	$A\bar{B}\bar{C}DEFG$	152	151	128	4.960	$\bar{A}BCDEFG$	177	176